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TITLE OF THESIS... Analysis of the Lower Back With Isometric, Concentric and Eccentric Training

UNIVERSITY... of Alberta

DEGREE FOR WHICH THESIS WAS PRESENTED... PhD

YEAR THIS DEGREE GRANTED... Fall 1973

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THE UNIVERSITY OF ALBERTA

ANALYSIS OF THE LOWER BACK WITH ISOMETRIC, CONCENTRIC, AND ECCENTRIC TRAINING

by

© THOMAS EDWIN JAMES ASHTON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICAL EDUCATION

EDMONTON, ALBERTA

FALL, 1973

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Analysis of the Lower Back with Isometric, Concentric, and Eccentric Training" submitted by Thomas Edwin James Ashton in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

The purpose of this study was to determine the effects of maximal isometric, concentric, and eccentric back-lift strength training on maximal back-lift strength; lumbar spinal curvature; and erectores spinae electromyograms during the three types of contractions with the back 20 degrees from vertical. Heart rate was recorded during and immediately following contractions. A sub-problem was to measure the maximal isometric hip flexion strength at a 160 degree hip angle before and after training. An electrogoniometer was used to measure hip angle. Three training groups and a control were compared.

Forty male students at the University of Alberta were ranked on total lifting strength and randomly blocked into one of four groups. All training subjects performed three maximal three-second contractions three days per week for five weeks.

The study consisted of four test sets. The isometric test set involved one maximal isometric back-lift at a hip angle of 160 degrees; and one maximal isometric hip flexion strength test at the same angle. The concentric test set consisted of one maximal concentric back-lift through a hip angle of 150 to 170 degrees; while the eccentric test set involved one maximal eccentric back-lift through a hip angle

of 170 to 150 degrees. The isometric test set for efficiency was performed at post test only and consisted of equalling one's original pretest isometric back-lift score. All measurements were made with the back 20 degrees from vertical (i.e., 160 degree hip angle).

In the isometric test set, analysis of covariance yielded significant strength differences at post test between each training group (all training groups increasing significantly) and the control group. Significant gains were made by the isometric and concentric group on lumbar erectores spinae mean peak voltage after training. No significant differences were found for lumbar spinal curvature or heart rate. The isometric group made a significant improvement on maximal isometric hip flexion strength.

For the concentric test set, analysis of covariance also yielded significant strength differences at post test between each training group (all training groups increasing significantly) and the control group. Analysis of covariance also showed that the eccentric and concentric groups had significantly higher post test mean peak voltages than the control group. All three training groups had increased significantly on lumbar erectores spinae mean peak voltage after training. No significant heart rate differences were found.

In the eccentric test set, analysis of covariance

showed that the strength of the eccentric group at post test was significantly higher than the control and isometric groups; and that the mean peak voltage of the eccentric gropu was significantly higher than the other three groups. Significant strength gains were made by the eccentric and concentric group; and the eccentric group on mean peak voltage. No significant differences were found for heart rate.

In the isometric test set for efficiency, analysis of covariance yielded no significant differences on lumbar curvature, mean peak voltage of erectores spinae, or heart rate. Significant reductions in lumbar curvature were made by each training group.

ACKNOWLEDGEMENTS

Sincerest appreciation is extended to Dr. Mohan Singh for his continued interest and guidance to the completion of the manuscript, and to Dr. Maury Van Vliet, Dr. Gerry Glassford, and Dr. Russ MacArthur, members of the committee.

A special thanks to Dr. Benjamin Ricci for his co-operation in serving as external examiner, and to David Reid for his direction throughout the developmental stages of the research.

My heartfelt gratitude is expressed to my parents, brother, wife Shannon and son Shane, for their tremendous source of inspiration, understanding, and meaning during my years at university as a student.

Appreciation is also expressed to Susan Schultz in typing the manuscript, and to those forty volunteers who made this study all possible.

The study was supported in part by the research grants from the Medical Research Council of Canada and the Department of National Health and Welfare, Ottawa.

TABLE OF CONTENTS

CHAPTER		PAGE
I	STATEMENT OF THE PROBLEM	1
	Introduction	1
	The Problem	4
	Limitations of the Study	6
	Delimitations of the Study	7
	References	9
II	REVIEW OF THE LITERATURE	12
	Back and Lifting Strength	12
	(1) Static and Dynamic Strength	12
	(2) Related Factors	16
	Lifting Stress and Spinal Curvature	21
	(1) Cadaver Studies	22
	(2) Engineering Models	24
	(3) Studies on Living Subjects	26
	Electromyography of Lifting	30
	(1) The Back and Lifting	30
	(2) EMG and Muscle Tension	34
	(3) Strength and Fatigue	35
	Cardiovascular Response to Lifting (Heart Rate and Blood Pressure)	37
	(1) Studies Involving Loads and Lifting	38

CHAPTER		PAGE
	Exercise and Training for Lifting and Backstrength	41
	(1) Strength Studies	41
	(2) Training and EMG's	44
	(3) Cardiovascular	45
	Electrogoniometry and Lifting	46
	References	47
III	METHODS AND PROCEDURES	57
	Subjects	57
	Experimental Design	57
	Anthropometrical Data	58
	Procedures for Administering the Tests	59
	Training	62
	Experimental Apparatus	64
	Calibration of the Apparatus	68
	Statistical Treatment	69
	Pilot Study	69
	References	70
IV	RESULTS AND DISCUSSION	71
	Analysis of Data	71
	Discussion	100
	References	113
V	SUMMARY AND CONCLUSIONS	116
	Summary	116

CHAPTER PAGE

Conclusions..... 119

Recommendations..... 121

BIBLIOGRAPHY..... 122

APPENDIX A - RAW DATA..... 133

APPENDIX B - FORMULAE..... 148

APPENDIX C - DATA COLLECTION SHEET..... 150

APPENDIX D - ANTHROPOMETRICAL DATA..... 153

LIST OF TABLES

TABLE		PAGE
I	Reliability Coefficients.....	72
II	Reliability Coefficients.....	72
III	Standard Error of Measurement - Summary....	73
IV	Means of Variables by Test Sets (Pretest)..	74
V	Means of Variables at Pre and Post Test - Isometric Test Set.....	76
VI	Analysis of Covariance - Summary Maximal Isometric Back-Lift Strength.....	77
VII	Tests on Differences Between Pairs of Means for Maximal Isometric Back-Lift Strength.....	78
VIII	Analysis of Covariance - Summary Lumbar Spinal Curvature.....	79
IX	Analysis of Covariance - Summary EMG Mean Peak Voltage.....	79
X	Analysis of Covariance - Summary Heart Rate.....	80
XI	Analysis of Covariance - Summary Maximal Isometric Trunk-Flexion Strength.....	80
XII	t-Tests and Probabilities - Isometric Test Set Between Pre and Post Test.....	81
XIII	Correlation Matrix and Probabilities - Isometric Test Set.....	83
XIV	Means of Variables at Pre and Post Test - Concentric Test Set.....	84
XV	Analysis of Covariance - Summary Maximal Concentric Back-Lift Strength.....	85
XVI	Tests on Differences Between Pairs of Means for Maximal Concentric Back-Lift Strength.....	86

TABLE		PAGE
XVII	Analysis of Covariance - Summary EMG Mean Peak Voltage.....	87
XVIII	Tests on Differences Between Pairs of Means for EMG Mean Peak Voltage.....	88
XIX	Analysis of Covariance - Summary Heart Rate.....	89
XX	t-Tests and Probabilities - Concentric Test Set Between Pre and Post Test.....	89
XXI	Correlation Matrix and Probabilities - Concentric Test Set.....	90
XXII	Means of Variables at Pre and Post Test - Eccentric Test Set.....	91
XXIII	Analysis of Covariance - Summary Maximal Eccentric Back-Lift Strength.....	92
XXIV	Tests on Differences Between Pairs of Means for Maximal Eccentric Back-Lift Strength.....	93
XXV	Analysis of Covariance - Summary EMG Mean Peak Voltage.....	94
XXVI	Tests on Differences Between Pairs of Means for EMG Mean Peak Voltage.....	95
XXVII	Analysis of Covariance - Summary Heart Rate.....	96
XXVIII	t-Tests and Probabilities - Eccentric Test Set Between Pre and Post Test.....	96
XXIX	Correlation Matrix and Probabilities - Eccentric Test Set.....	97
XXX	Means of Variables at Pretest and When Pretest Isometric Back-Lift Strength Repeated After Training - Isometric Test Set for Efficiency.....	98
XXXI	Analysis of Covariance - Summary Curvature.	99

TABLE		PAGE
XXXII	Analysis of Covariance - Summary EMG Mean Peak Voltage.....	99
XXXIII	Analysis of Covariance - Summary Heart Rate.....	100
XXXIV	t-Tests and Probabilities - Isometric Test Set for Efficiency Between Pre and Repeated Pretest Isometric Back-Lift Strength After Training.....	101

LIST OF FIGURES

FIGURE		PAGE
1	Method of Measuring Lumbar Spinal Curvature.....	61
2	Experimental Apparatus and Subject.....	63
3	Sample Recording for Three Types of Back-Lift Strength.....	66

CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

> "The low back pain syndrome affects probably 80 per cent of the members of the human race at some time in their lives. Although it rarely results in mortality, its morbidity is high, inconvenience great, and economic burden significant. Its prevention is aided by posture training in the schools, safety engineering, and physical fitness consciousness in general (6)."

With lifting, mechanics, neuromuscular and vertebral structures and functions of the spine are all deeply involved. Since the human spine is such a complex structure, it is very difficult to explain physiologically the various back injuries - their exact sites, precise causes, and multitudinous interrelationships. Although it is a single functioning unit, the spine's skeletal, muscular, and neural interrelationships are of an almost infinite number. Physical training and exercise may lessen the risk of back injury, but research concerning the benefits achieved through training is lacking.

The lumbar spine has associated with it a certain degree of curvature, and most flexion and extension occurs here. Seventy-five per cent of flexion occurs at the lumbosacral interspace; 15-20 per cent at L4-L5, and 5-10 per cent from L1 to L4 (6). The sacral angle is important because it determines the curvature which the lumbar spine must take in

order to keep the centre of gravity of the body over the feet. Normally the curvature in the lumbar region is more pronounced than the other two curves of the spine.

The greater the degree of curvature; the greater the shear stress will be. If the fifth lumbar vertebra takes an angle of 30, 40, and 50 degrees from the horizontal, the shear stress will be 50, 60, and 75 per cent of the superincumbent weight (6). This shear stress acts parallel to the vertebra. In effect the vertebra is tending to slide off the vertebra (in this case the sacrum) below it against the ligaments, vertebral end plates, etc. This force is more dangerous than compression (15).

It has been found that the strength of the back, as far as the force exerted, increases with training (2,4,7,12, 13,14,19,29). These studies have dealt mainly with static (isometric) training. This increase in strength has been reflected in electromyograms, and their electronic integration, involving the lumbar erectores spinae (7,8).

Studies have shown that the intra-abdominal pressure contributes a great deal in aiding the spine to support or lift weights (3,10,16,23). However one is left with the question of whether or not this body cavity pressure could possibly be increased; and if so, by how much through training.

In calculating the curvature and resulting stresses in the lumbosacral spine, a great deal of work has been done on cadavers concerning compression forces (5,15,17,23,25). This obviously eliminates the factor of training completely.

Extensive work has been done in developing mathematical models for predicting spinal injuries during a variety of human body impacts, and in particular the seat ejection problem. The models have been either lumped-parameter models consisting of springs and masses in series, or continuum-rod models (1,18,20,21,22,27,28). However most of this research deals with uniaxial compression. It has not been until recently that Orne and Liu (24) have been able to shed much light on the shear effects associated with the natural curved shape of the spine in a mathematical model. Theoretical research, as in the preceding studies, is of questionable value. That is to say, the human spine is not a series of springs and dashpots. These inanimate mathematical models, in addition, allow no room for training considerations to be studied.

Research dealing with compression and shearing stress in regard to living subjects is definitely lacking. What little has been done has neglected the possible training factor completely. In other words, what curvature changes, if any, might occur in a lumbar spine that has undergone a strict training regime? The model used by Eie and Wehn (16) and Eie (15) to calculate the resultant compressive force on the fifth lumbar intervertebral disc and vertebra during the lifting and holding of weights is limited. In their model, the authors assume that the weight bearing has been carried out with the vertebral bodies parallel to each other (the back in a straight line). With the spine there is always

a certain degree of curvature. This inherent weakness would undoubtedly have affected their calculations to some degree. Davis et al (11) and David et al (9) used chronocyclophotography and cinematography respectively to analyze the thoracic and lumbar spinal movements under differing magnitudes of weight lifted and different lifting methods. However, no attempt was made to calculate spinal forces under any states of curvature. These two studies, along with the previous two, exclude any possible effects due to training.

The Problem

In order to better study spinal stresses, the curvature of the back must be taken into consideration. The lumbosacral angle and the resultant lumbar curvature determine the compression and shear stress associated with the lower back during lifting. That is to say, the more pronounced the curvature; the greater will be the ratio of shear to compression, and vice versa. Can training possibly alter this curvature and the associated shear-compression ratio? If training can lower the shear force (which is the more difficult of the two for the back to cope with) in favour of compression (with lessened curvature) when lifting weights; one could, through training, learn to lift more efficiently and lessen the risk of injury. In other words, can the spine be trained to withstand stress?

Although x-rays would provide a direct analysis of spinal curvature during lifting before and after training;

their use involving normal healthy individuals is ethically forbidden due to possible radiation effects, especially on the reproductive organs.

This study will be concerned with determining the effects of maximal isometric, concentric, and eccentric back-lift strength training on maximal isometric, concentric, and eccentric back-lift strength; lumbar spinal curvature during maximal isometric back-lifting; and erectores spinae electromyograms during maximal isometric, concentric, and eccentric back-lifting at a hip angle of 160 degrees (flexion). In addition, the pretest maximal isometric strength score will be repeated at post test by each subject in order to look at any changes in efficiency. A sub-problem will be to administer a maximal isometric hip-flexion test at a 160 degree hip angle before and after training to assess the effects of training the agonists (back extensors) on the strength of the antagonist muscles (trunk flexors). Heart rate will also be recorded immediately following each maximal isometric, concentric, and eccentric contraction. An electrogoniometer will be used to measure the subject's hip angle throughout all the tests. Three different training groups and a control will be compared.

The null hypotheses for the problem are:

(1) That any changes in maximal isometric, concentric, and eccentric back-lift strength due to training shall be similar for maximal isometric, concentric, and eccentric back-lift strength training. H_0: $u_{1A} = u_{2A} = u_{3A}$.

(2) That any changes in lumbar spinal curvature during maximal isometric back-lift strength due to training shall be similar for maximal isometric, concentric, and eccentric back-lift strength training. H_0: $u_{1B} = u_{2B} = u_{3B}$.

(3) That any changes in erectores spinae electrical activity during maximal isometric, concentric, and eccentric back-lift strength due to training shall be similar for maximal isometric, concentric, and eccentric back-lift strength training. H_0: $u_{1C} = u_{2C} = u_{3C}$.

(4) That any changes in heart rate during maximal isometric, concentric, and eccentric back-lift strength due to training shall be similar for maximal isometric, concentric and eccentric back-lift strength training. H_0: $u_{1D} = u_{2D} = u_{3D}$.

(5) That any changes in maximal isometric hip-flexion strength due to training shall be similar for maximal isometric, concentric, and eccentric back-lift strength training. H_0: $u_{1E} = u_{2E} = u_{3E}$.

Limitations of the Study

(1) Errors in calibration, testing precision, and standardization.

(2) Errors in external measuring of lumbar spinal curvature.

(3) Degree of repeatability of pretest with post test in terms of standardization of body position.

(4) The number of variables measured.

(5) The 'shout method' will be used for motivation.

Delimitations of the Study

(1) The study will be delimited to a sample of 40 male physical education student volunteers at the University of Alberta. Their ages range from 21 to 40 years (average = 23.4 years).

(2) Measurements will be analyzed at one hip angle (160 degrees) in the back-lift test situation (26) modified to include concentric and eccentric strength training and testing as well as isometric.

(3) The study will be delimited to the measurement of the following variables: back-lift strength, lumbar spinal curvature, erectores spinae electromyograms, heart rate, and trunk flexion strength.

Definition of Terms

Isometric Strength. The force exerted by a contraction in which the length of the muscle does not change appreciably.

Concentric Strength. The force exerted by a contraction in which the muscle shortens its length.

Eccentric Strength. The force exerted by a contraction in which the contracting muscle is lengthened due to an externally imposed force.

Back-Lift. A test of the back-lift strength of the extensor muscles of the back by having the subject, with legs straight, left vertically and maximally with his back and recording the lift score on a back dynamometer.

Experimental Back-Lift Method. The back-lift test using

a steel bar about 20 inches long and one inch in diameter with a steel hook attached at the midpoint on the bar, a load cell, a length of cable, and the experimental back-lift dynamometer.

Lumbar Spinal Curvature. The sum of the change in curvature between the first and fifth lumbar vertebra measured in degrees.

Compression Force. The component of force applied in the line of gravity with the back that acts perpendicular to the disc.

Shear Force. The component of force applied in the line of gravity with the back that acts in the plane of the disc.

Electromyogram. The recording of the 'muscle action potential' or electrical charge that accompanies the contraction of muscle tissue.

Efficiency. Lifting with a relatively lower muscle action potential and heart rate, and with a straighter lumbar spine.

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CHAPTER II

REVIEW OF THE LITERATURE

Back and Lifting Strength

(1) Static and Dynamic Strength

Static Strength. Many authors have measured the external forces exerted during static (isometric) contraction of the muscles of the trunk; the majority recording the strength of the maximal back-lift (pulling vertically on the handles of a back dynamometer). Hinojosa and Berger (52) did a study on fifteen male college students to determine what techniques of grasping the handle bar would result in the highest back-lift strength score. The means for the methods of no tape on bar, no-tape-hold (tester holding subject's hands), tape, tape-hold (tester holding subject's hands), and hands strapped to the bar were 384,66, 364.66, 421.33, 431.33, and 458.00 pounds respectively. In other words, there was an increase in the recorded back-lift strength as friction increased between the hands and bar, with the exception that the no-tape mean exceeded the no-tape-hold mean by twenty pounds. Singh and Ashton (89) employed a shoulder harness to eliminate the use of hands and arms, and compared results with the traditional back-lift test (as in the Rogers' P.F.I. test battery) on twenty-four college males. The means

of the best scores for the two methods were 374.17 and 362.29 pounds respectively. However this difference was not significant.

To eliminate the effects due to gravity in maximal isometric back strength, Troup and Chapman (100) developed a dynamometer and anterior pelvic bar in order to measure the maximal isometric pulling force of the back extensors and flexors in the standing and sitting position during one-second contractions. The forces exerted by the males were significantly higher than those exerted by females, both in absolute terms and when expressed as a proportion of the body weights of the two sexes. In standing, the mean maximal extensor force for men was 98 kilograms. The corresponding value for flexor force was 75 kilograms - the flexor forces being consistently less in magnitude than the extensor forces. In a similar study done on thirteen male medical students, Chapman and Troup (19) found the mean maximal pulling force of the back to be 96.5 kilograms. External forces applied to the dynamometer were estimated to be within three per cent of the indicated value.

Clarke (20) has developed and employed a cable-tensiometry technique, 'trunk extension', to test the isometric extension strength of the back. The testing is done on a table with a twenty-inch by seven-inch cut lengthwise in the centre to permit the attachment of a pulling assembly below the subject. A trunk strap is placed around the subject's back and is hooked to the pulling assembly below the

table, with the subject in a prone position (hands folded over the small of the back). The subject extends his trunk maximally against the cable and the score is recorded on the cable tensiometer. For sixty-four non-disabled male students at Springfield College, the mean score was 234.66 pounds. For this method the results are much lower than for the back-lift. Hutchins (54) has used Clarke's method on female university students at the University of Oregon where she obtained a mean of 55.83 pounds. Using college males at the University of Oregon, Kennedy (57) found the objectivity coefficient for the back-lift with the tensiometer to be 0.90 which compared favourably with the test-retest reliability estimate of 0.88 using the dynamometer. The tensiometer yielded slightly higher back-lift scores than did the dynamometer.

Strain-gauge techniques have also been involved in static back-strength testing. Morris et al (74) had subjects, with knees straight, pull against a strain ring with the trunk vertical and then flexed at 30, 60, and 90 degrees. The mean tension exerted was 177.7, 164.75, 161.33, and 148.25 pounds for the four positions respectively. Kennedy (58) compared strain gauge readings with those from the cable-tensiometer during 378 observations on weight lifting of from 10 to 180 pounds. Strain-gauge readings were greater than those from the tensiometer in 69.1 per cent of the tests. In the mid-range values, recordings from both instruments closely approximated each other.

Dynamic Strength. The dynamic (isotonic) strength of the back and trunk muscles has been given little attention. Kraus (61) devised a series of tests of the activity of the trunk muscles, but their interpretation was made qualitatively.

Delorme (29) used heavy resistance exercises in the form of a hyperextension exercise performed on a spinal back exerciser with subjects in the prone position. Resistance through extension could be increased progressively be adding weights to a weight pan attached to the back. Berger (8) determined the dynamic strength of 78 male students at the University of Illinois by means of a similar back hyperextension lift. The weight of the barbell, placed behind the neck, was increased by ten pounds after each successful lift until the maximum load was approached. From then on the increases were five pounds, with at least three minutes rest between trials. The mean dynamic strength recorded was 75.62 pounds; and the correlation coefficient between actual static and dynamic strength was 0.622. In dynamic tests of strength in which the torque transmitted by the muscles of the trunk in rotator activities has been measured using cinematographic techniques, it has been found that the torque developed in 0.10 second periods is in excess of the maximal isometric torque (100). To overcome the inertia of a load in heavy manual dynamic tasks as in lifting, it appears that muscular activity should be coordinated so that at critical points of time the prime movers are contracting eccentrically in order

to develop the greatest tension.

Investigations of concentric and eccentric muscle contractions has been mainly concerned with elbow flexors and extensors. Singh and Karpovich (93) found that, for men, the average strength of extensors expressed as a percentage of flexor strength was 53-55 per cent for concentric, 47-48 per cent for eccentric, and 52-57 per cent for isometric contractions. The same authors (92) tested twenty male physical education students and discovered that eccentric forces of flexors and extensors were 32.65 per cent and 14.22 per cent greater than the concentric forces respectively. In a study involving hip abductor muscles done on thirty normal male subjects averaging 24 years of age, Olson et al (76) concluded that the eccentric contraction develops the greatest tension of the three types with the isometric and concentric following in that order through a range of 40 degrees of abduction to 10 degrees of adduction. Corresponding results for lifting and back-lift strength in concentric and eccentric contractions are lacking.

(2) Related Factors

Age. In a study done by Clarke and Wickens (22) on forty boys, at each age from nine to fifteen, from Caucasian public schools in Medford, Oregon, the back-lift mean growth curve was derived. The curve had a relatively slight increase during ages nine to ten, a deceleration at eleven years, a pronounced and nearly straight line rise from ages

eleven to fourteen, and some deceleration at the age of fifteen years. The mean back-lift of the fifteen year-olds was more than twice as large as the nine year-olds (148 vs. 69 kilograms). The standard deviations increased with age.

In a similar study on 125 native Indian boys in the Province of Alberta, Singh et al (90) found the back-lift mean growth curve to have a relatively slight increase during ages nine to eleven, a slightly greater increase from eleven to thirteen years, and an even more pronounced rise from ages thirteen to fifteen. From 20-29 years it continued to rise, and fell from 30-39 years to 50-62 years. The standard deviations also increased with age except at eleven years.

In adults maximum isometric strength is attained at about 30 years of age and then decreases with age, especially in large muscles of the leg and trunk. Mean trunk extension values on 600 Danish male adults at 20, 25, 35, 45, and 55 years of age were 81.6, 87.4, 90.7, 89.8, and 85.7 kiloponds respectively (41). In a dynamometer strength study of males thirty to seventy-nine, Donnelly (35) concluded that adults participating in recreational sports were stronger than non-participants. Among those participating, the ones who were athletes in high school or college were stronger in back and total strength than non-athletes.

Somatotype and Anthropometry. On the back-lift item, means of 381.20 pounds for ectomorphs, 406.90 pounds for endomorphs, and 475.30 pounds for mesomorphs were attained by Sills and Everett (88) in their study on forty-three

University of Iowa students. They concluded that the mesomorphs were stronger than the endomorphs and ectomorphs; that the endomorphs were stronger than the ectomorphs although statistically significant differences were not obtained; and that excess weight is a handicap to endomorphs and insufficient strength a handicap to the ectomorphs in performing physical tests.

Asmussen and Heeboll-Nielsen (3) found that muscular strength of the back increases exponentially with increasing height, and that overall back strength correlated highly to the strength of other muscle groups. Clarke (21) correlated back-lift strength with various anthropometric measures. In his study on fifty-three non-disabled male students at the University of Oregon, back-lift strength correlated 0.61 with hip width and knee extension strength, 0.58 with body weight, 0.51 with trunk-flexion strength, and 0.50 with trunk lateral-flexion strength. These results were all significant beyond the 0.01 level. A multiple correlation of 0.71 was obtained between the back-lift strength and knee-extension strength, hip width, trunk-flexion strength, and knee-flexion strength.

Body Position and Angle of Pull. Pulls from below, oblique the axis of the trunk (as in the back-lift), have a component which compresses the vertebral bodies and discs permitting especially strong pulls. Dempster (30) studied the strength of pulls at different angles from the vertical in lifting. Few pulls of 45 to 30 degrees from the vertical

reached 350 to 400 pounds; whereas, pulls at 30 degrees were the strongest. As the trunk straightened further, the pull vectors were found to decrease. Singh and Ashton (89) recorded maximal pulls at about 20 degrees from the vertical. According to Vernon (102) the strength of pull decreased as the grip height increased from the ankle joint to a low at about fifteen inches (just below the tibial tuberosity); then increased markedly to over 300 pounds at a height of twenty-seven inches (finger tip height when the subject stood erect); and finally decreased for the next several inches. According to Davis (26), the theoretical maximum lift in the most ideal position (around 30 degrees) is approximately 500 pounds.

Posture. Flint and Diehl (45) in testing 210 school girls from three Santa Barbara elementary schools found a relationship between the strength of the back extensor muscles and antero-posterior alignment of the trunk to be significant at the 0.05 level. However, Flint (44) found no significant relationship between the position of the gravity line and back-muscle strength when testing 117 elementary school girls (six to twelve years old) from three Santa Barbara City elementary schools.

Asmussen and Heeboll-Nielsen (3) concluded that a strong and flexible back most often has more pronounced curves. On the other hand, the Department of Hygiene and Physical Education at Harvard University (103) associates its A rating (strongest back) with rather flat backs. Little

has been pursued in this relationship and any effects due to training.

It was shown by Troup and Chapman (100) that the extensor turning moments on the trunk were markedly greater when sitting than when standing. In sitting, the length of the effective lever was reduced compared with the standing posture. When flexed, the tips of the spinous processes are prominent posteriorly; and in the extended posture, the lumbar erectores spinae form two bulky ridges which are posterior to the spinous processes. Thus the centre through which the extensor forces are transmitted is situated more posteriorly and with a longer lever for action than when sitting. However, the difference has not been measured.

Rhythm and Speed of Contraction. Rhythm (slow steady lifting) has been found by Ronnholm (84) to play a major role in mechanical efficiency. In his study involving two sportsmen lifting various weights through different distances, a constant rhythm was much more efficient and resulted in a lesser increase in energy consumption as more muscles were recruited with an increased load.

Rasch and Burke (82) found that the internal force exerted by the back extensors decreased with an increase in the velocity of contraction according to an exponential law; and that in maximum lifting this rate must be very slow. Zajaczkowska (104) showed that with training this velocity increased very slightly and then levelled off as a constant value to produce maximum lifts. He concluded that skill in

lifting consists of reducing the acceleration of back extensor contractions to zero.

Endurance. There is some evidence to indicate that a relationship between maximum back strength and relative muscular endurance of the back is negative and generally significant. Tuttle et al (101) found significant negative correlation coefficients of -0.40 and -0.48 between maximum strength and the average proportion of maximum back-strength able to be maintained for one minute. They concluded that stronger subjects had a greater absolute endurance but were unable to hold as high a relative ratio of held-to-maximum than weaker subjects.

Caldwell (13), on the other hand, found a range of intercorrelations of 0.36 to 0.88 between strength of pull and endurance (80 per cent of maximum force) for twenty different experimental conditions. Later Caldwell (14) showed that when subjects were required to hold a force proportionate to maximum isometric strength there was no relationship with strength endurance. Shaver (86) tested forty male physical education student volunteers at the University of Maryland and also found no significant relationship between maximum isometric strength gains and relative muscular endurance gains.

Lifting Stress and Spinal Curvature

The force applied in the line of gravity with the back may be resolved into two components: (1) a compressive force

acting at 90 degrees to the disc, and (2) a shear force acting in the plane of the disc. The compressive component is highest when the disc is at right angles to the line of gravity (straight back) and is diminished as the inclination of the disc increases (curved back).

(1) Cadaver Studies

In calculating compression and shear forces in the lumbosacral spine, a great deal of work has been done on cadavers - mainly to do with compression. Brown et al (11) found that the ultimate axial compression load for lumbar discs tested ranged from 1000 to 1300 pounds with failure taking place in the vertebral end plates. In two studies by Morris et al (74) and Perey (79), average values for fractures of vertebrae and rupture of discs in adults ranged between 704 and 1716 pounds, with the end plates being weaker than both the vertebral body and annulus fibrosus. In eighteen experiments, fifteen of which involved lumbar vertebrae and discs, Eie (37) found that the first sign of damage always appeared in the vertebrae, and in some cases no sign of damage of the intervertebral disc wall or end plates was seen even after fracturing of the vertebrae. The author found that the resistance of the lumbar spine to bending forces and shear was low compared to the resistance to compression - in this regard a bony fused area seemed to be stronger than other parts of the spine. Evans and Lissner (40) found that much more energy can be absorbed in compression than in bending

where shear force is involved - this being a factor for consideration with regard to spinal injury during vertical loading and bending moments.

Markolf (72) analyzed the response of twelve lumbar discs during compression up to 450 pounds. The compression curve showed progressive stiffening with increasing vertical deflection up to 0.5 inches at 450 pounds compression. This great stiffening observed in all the discs tested might be expected as the result of the hydrostatic pressure generated within the nucleus during compression. Curves of shear force against transverse displacement on eight lumbar intervertebral discs were fairly linear but varied widely from specimen to specimen. Shearing displacements reached values of 0.03 inches at shear forces of 46 pounds; but shear stiffness (represented by the slope) was so great, the applied shear force was limited to avoid excessive bone deformation.

Hoag and Rosenburg (53) estimated that the load (compression plus shear components) on the disc between L4 and L5 just during forward bending is about 400 pounds. Farfan and Huberdeau (42) studied the inclination of the lumbar discs with reference to the long axis of the spine, as well as the degree of the lumbar curve on 182 whole lumbar spines. With respect to the disc space between the third and fourth lumbar vertebra, the space between the first and second was inclined backward an average of 11 degrees (range: 0 to 39 degrees), and the space at the lumbosacral level was inclined forward an average of 32 degrees (range: 7 to 48 degrees). The lumbar

curve (the angle subtended by the planes of the disc spaces between the first and second lumbar and between the fifth lumbar and first sacral vertebra) ranged from 10 to 67 degrees, the commonest angle being 42 degrees. The lumbar curve was the same in both sexes and appeared to be independent of age, at least over the age of forty years. There were too few specimens below the age of forty to give any indication of the incidence below this age. The sacral inclination followed the same pattern as the lumbar curve, being independent of age and sex. A decreased inclination of the lumbosacral joint was associated with lesser lumbar curvature and accompanying shear force.

(2) Engineering Models

Extensive work has been done in developing mathematical models for predicting spinal stresses and injuries during a variety of human body impacts, in particular the pilot ejection problem. Of the lumped parameter models consisting of springs and masses in series, Latham's (62) represented the spine as a weightless spring with rigid masses attached at the upper and lower ends to simulate the masses of the man and the supporting structure respectively. Being a linear, single-degree-of-freedom model, it was restricted in that it could only predict a uniform axial force along the spine and was unable to single out the lower or middle thoracic region as being the sites of most spinal injuries in pilot ejection.

Toth (99) rectified this short-coming by using a model

consisting of eight mass elements, simulating the eleventh thoracic vertebra through the fifth lumbar vertebra, as well as the pelvis. Using assumed values for the failure threshold of the indíviduál vertebrae, he evaluated the likelihood of structural damage to each vertebra only in axial response.

Aquino (1) developed a model consisting of a series of lumped segments connected by linear springs and dashpots to predict the dynamic response of the lumbar spine. The author made comparisons between his model and a validation experiment performed on isolated lumbar spines of Rhesus monkeys. Both the bending and tensile (compression) stiffnesses were assumed linear in the model. For compression, each lumbar vertebrae pair was loaded at a constant strain rate till the spacing between the vertebrae was 0.046 inches greater than the equilibrium value. In every case studied, the predicted compressive force was lower (from 2 to 60 pounds) than the measured compressive force (measured up to 160 pounds), although both were fairly linear. In some cases, the actual tensile force in the actual spines reached a value almost twice as large as the model. The author concluded that this dynamic overshoot was due to elasticity of the spine. The bending moment versus angular motion was obtained by applying a steadily increasing moment up to about 32 inch-pounds. The bending stiffness was highly non-linear in comparison to the model's assumption of linearity and made prediction by the model difficult. At a bending of 9.25 degrees of angular motion, the corresponding mean bending moment on a vertebrae

pair was approximately 31.88 inch-pounds of force. The author concluded that any success using linear bending characteristics was due to the low range of bending experienced, and that the attempt at linear approximation of the model to actual bending moments would have to be replaced by a more accurate representation if a wider range of conditions were to be studied.

It has not been until recently that any significant light has been shed upon data for shear and bending of the spine corresponding to axial compression tests. Orne and Liu (77) employed a discrete-parameter model in their investigation, with as many as twenty-five rigid masses in the system, each having degrees-of-freedom in three planes during seat ejection. Under a maximal axial compression of 1100 pounds per square inch and a constant strain rate of 72 pounds per square inch per second, the shear force after 90 milliseconds was calculated to be 600 pounds at the base of L5 (1200 inch-pounds) and 400 pounds at the disc between vertebrae T9 and T10. The authors concluded also that the effect of bending due to the presence of spinal curvature is appreciable.

(3) Studies on Living Subjects

The muscles of the trunk transmit considerable forces in the course of daily physical activities, but little is known of their magnitude. Strait et al (95) assessed the tension of the erectores spinae muscles of a 180 pound man in lifting his back from a position 60 degrees from the verti-

cal. If his fifth lumbar vertebra is considered a fixed fulcrum; if the weight of his head and arms combined is 20 per cent of his body weight (36 pounds), and his trunk 40 per cent of body weight (72 pounds); and if the distance from his fifth lumbar vertebra to the point of action of the weight of his arms and head is 'L'; it was calculated that the effective tension of the erectores spinae acting at 12 degrees with the spine would be in the neighbourhood of 450 pounds. If he lifted a 50 pound weight, the tension would increase to 750 pounds. The corresponding compression force on the fifth lumbar vertebra was approximated at 850 pounds. At this 60 degree angle, the resultant force was nearly parallel to the spine making the strain on the disc at the fifth lumbar vertebra primarily compressional with some shear due to a tension stress on the convexity of the lumbar region as a pressure stress on a bending beam (94). As the angle and curvature are increased, so is the shear force or the possibility of one vertebra sliding off another vertebra (12).

Morris et al (74) calculated theoretically that the intra-abdominal pressure could reduce the pressure on the intervertebral disc by about 40 per cent. Eie and Wehn (38) demonstrated that a muscular individual could produce abdominal pressures of 225 mm. Hg. while lifting 130 kilograms with a relieving force of approximately 180 kilograms. The resultant compressive force perpendicular to the fifth lumbar vertebra was 323.5 kilograms. In an average muscular athlete who lifted 40 kilograms, an intra-abdominal pressure of 125 mm.

Hg. was registered with a relieving force of 83.6 kilograms. The resultant perpendicular force on the person's fifth lumbar disc was 111.3 kilograms.

Groh et al (50) analyzed the extensor and compressive forces at the lumbosacral level in a male subject, weighing 76 kilograms and 182 centimeters in height, in eight postures, omitting the possible effects of raised intra-abdominal pressure. The extensor force was estimated as zero when standing erect; and at 350 kilograms and 1590 kilograms when holding weights of 25 kilograms and 200 kilograms respectively in a stooping posture with knees flexed.

Using the model of Morris et al (74), Fisher (43) calculated the compressive forces transmitted by the back extensor muscles from photographic records. The maximal estimated forces in the course of lifting 40 pounds from the floor with trunk and knees flexed in an average sized man was 451 kilograms at the lumbosacral level. Lifting a 50 pound weight with knees extended produced maximal calculated forces at this level of 427 kilograms and 345 kilograms in an average sized man and woman respectively.

Davis et al (28), by means of a chrono-cyclophotographic technique involving pointers projecting from the spinous processes at T1, T12, and S1, investigated the timing and amplitude of thoracic and lumbar extension in the sagittal plane on healthy adult males while lifting weights up to 40 kilograms in stooped and bent-knee positions. They found that the lumbar spine initially flexed, then extended continuously

throughout the lift, with the extension beginning when the weight had reached 1/4 to 1/2 its final height. In stooped lifting, this delay before lumbar extension was constant irrespective of the weight lifted; whereas, for bent knees, the delay was proportional to the weight lifted (i.e., more weight = more delay; less weight = less delay). There was little difference between the range of lumbar extension in the two methods of lifting; although the net extension was somewhat greater when lifting with straight legs.

David et al (25) synchronized cinematography (with the aid of pointers over the spinous processes) with electromyography to investigate spinal extension during straight-legged weight lifting. The authors also found that the initial movement of extension was in fact flexion. Throughout the lift, the greatest point of stress was seen to move with the point of maximum curvature of the spinal column. This point shifted from the region of T11 to the region of L2 throughout the lift; while the lumbosacral joint, considered fixed relative to the rest of the spine, was thought to be the fulcrum of spinal movement. The authors concluded that any attempt to lift heavy loads should be stopped immediately if the hips cannot be kept below the level of the upper body as the legs extend.

Troup and Chapman (100) calculated that, for a maximal extensor force while standing of 98 kilograms, the compressive force on the disc between the fourth and fifth lumbar vertebra equalled 667 kilograms. Addition of about 36 kilograms, re-

presenting the weight of the body above L4, produced a total compressive force of 703 kilograms. If the abdominal pressure could minimize the compressive forces here induced by as much as 25 per cent (27), then the theoretical forces considered here would be reduced to 500 kilograms and 527 kilograms respectively.

Electromyography of Lifting

The largest and most superficial muscle involved in extending the back is the erectores spinae muscle(s) consisting of the iliocostalis, the lateral branch; the longissimus, the middle branch; and spinalis, the medial branch (103). This muscle is responsible for extension of the entire spine (49,103), and being the most superficial is more amenable to surface electrode electromyography than the other back extensor muscles.

Immediately underneath the erectores spinae is the semispinalis thoracis muscle responsible for extending the thoracic spine (7,49,73). Underneath these muscles are the deep posterior muscles of the spine, including the multifidus, rotatores, and the interspinalis as well as the other small interconnecting muscle slips attached between pairs of vertebrae (103). The following will deal mainly with the superficial erectores spinae muscle(s).

(1) The Back and Lifting

In the fully flexed position, Evans (39) and Donisch

and Basmajian (34), using surface and fine wire electrodes respectively, found that the erectores spinae muscles were inactive and concluded that the ligamentous structures were assuming the load. Floyd and Silver (46), using needle electrodes, demonstrated that other deeper muscles did not help out in this position, concluding that when the erectores spinae muscles relax, all other deeper muscles relax also.

Extension from the position of total flexion was investigated by Thomas (97). EMG recordings were obtained at various segmental levels of the lumbar spine using insulated platinum-wire electrodes, and results demonstrated that there was a rapid discharge and powerful action current pattern of high amplitude recorded from the erectores spinae trunk extensors. Donisch and Basmajian (34) found 'short bursts' of activity in the lumbar region when the movement of extension was half completed. Morris et al (73) placed electrodes in the iliocostalis and longissimus branch of the erectores spinae in the lumbar region at L5. The muscles under consideration became more active as extension began and decreased in activity as the extended position was reached. Thomas (97) also found that activity was less in the normal upright position with very slight forward tilting. Portnoy and Morin (80) obtained similar findings except that there was a rise in erectores spinae activity until the erect position was reassumed.

In forced extension or in lifting weights from the fully-flexed position, the degree of activity seems more pro-

nounced. Floyd and Silver (46) found that when a person grasped and initially lifted a 28 pound weight in the fully stooped position, the erectores spinae muscles still remained relaxed with the ligaments taking up the additional strain. However, when the weight was lifted a bit higher, vigorous activity took place, slowly diminishing until the upright position was reached. In some cases, the authors found there was a burst of activity in the electromyogram just as the weight was lifted off the ground, and associated this with a grunting or straining effort which usually causes the back muscles to contract. Similar results were obtained by Pauly (78) who tested all three branches of the erectores spinae by inserting fine-wire electrodes by means of hypodermic needles. The longissimus contracted more vigorously than the iliocostalis branch, and the spinalis harder than the longissimus. The author concluded that the spinalis branch acted as the prime mover in the sagittal plane, while the other two branches were limited due to their mechanical advantage. In a study of a standard Olympic lift of 167.5 kilograms done by Corser et al (23), erectores spinae activity was greatest from the weight-leaving-the-floor position through to the low-control position; and lessened from the stand-erect position through to where the weight was held over the head with arms extended and standing erect. Morris et al (74) measured the electromyographic activity of the deep muscles of the back as subjects pulled on a strain ring up to a maximum of 200 pounds with trunk vertical and then

flexed at 30, 60, and 90 degrees. For static pulls at tensions on the strain ring of 200, 200, 180, and 170 pounds at 0, 30, 60, and 90 degrees from the vertical, the corresponding electromyograms reached voltages of approximately 6,000, 8,000, 7,000, and 8,000 microvolts respectively. When subjects lifted weights from 0 to 200 pounds in 50-pound increments, in the form of barbells, from the floor to the height of the freely hanging hand with the subjects in the erect position; the maximum voltages were 1,000 microvolts for 0 pounds, 3,000 for 50 pounds, 5,000 for 100 pounds, 7,500 for 150 pounds and 200 pounds respectively with maximum values occurring as the weight left the floor and decreasing as the vertical was reached. Results of an experiment done by Jonsson (55) on thirteen healthy subjects aged twenty to twenty-seven years showed that differences in the degree of EMG activity occurred between the longissimus and iliocostalis branches of the erectores spinae, and between different lumbar levels as well as between subjects. Standing with a load of 10 kiloponds held by both hands in front of the trunk gave a marked increase in activity in the lumbar part of the erectores spinae.

The position of the load seems to be very important. Carlsoo (15) found that, with the load in front of the thighs, the erectores spinae activity was greatly increased. Pauly (78) found similar results in a subject curling a 40-pound barbell. As the barbell was shifted forward, all the lower back muscles contracted vigorously in a descending order of

spinalis, longissimus, and iliocostalis. When the barbell was raised under the subject's chin, and in the lift-and-press position where the back became straight; the lower back muscle activity was reduced. As the weights were lowered to the floor, there was an increase in muscle activity.

(2) EMG and Muscle Tension

It has been shown that when a muscle contracts the mean voltage of the EMG recorded from its surface increases with the force of contraction - this relationship being linear provided the contraction is isometric (68,71). Falls (41) has found, by plotting mean peak voltages of known back muscle pulls isometrically, that EMG's will give a calibration best-fitting straight line from which muscle tension can be predicted from the voltage. For pulls of 10 to 70 kilograms, the corresponding mean peak potentials ranged from 20 to 180 microvolts using surface electrodes. Bigland and Lippold (10), using a planimeter to integrate the action potentials of calf muscles of the leg, also demonstrated this linear relationship between voltage and tension for submaximal isometric contractions. With isotonic contractions, the voltage depended also on the velocity of shortening of the muscle, so that the relationship only remained if that was held constant. Zuniga et al (105), on the otherhand, obtained results on the biceps muscle showing a non-linear progressively increasing electrical activity with increased isometric tension. Gottlieb and Agarwal (48) arrived at a simple linear

second-order differential equation with constant coefficients between muscle activity and tension on the soleus muscle. Grossman (51) suggests that the linear relationship may hold over certain ranges of contraction, but that the slopes obtained will be different depending on whether the contraction is isometric or isotonic; on the state of fatigue; where the electrodes are placed; and on inter and intra-individual differences. Therefore researchers should obtain values for the differences between resting and stimulus levels of action potentials, and compare these differences.

(3) Strength and Fatigue

Asmussen et al (4) showed a linear relationship between the integrated EMG and the forces produced by the activity of the erectores spinae; but the effects of increasing the strength of these muscles had apparently not been studied.

DeVries (32) studied increases in strength involving non-hypertrophy, and those where hypertrophy occurred. In the first case, the author suggested that strength increases were proportional to the increase in output of electrical activity; and in the latter, that strength increases led to a reduction in electrical activity for a given external force as hypertrophy increased the capacity of the muscle fibres to develop tension in the human biceps brachii without changes in the amplitude and frequency of the muscle action potentials.

In a study by Chapman and Troup (19), all subjects gained in back-pull strength during the investigation, the

mean gains after submaximal training (7.3 per cent) and maximal training (a further 7.2 per cent) both being significant. The linear relationship between the integrated EMG and the external force produced by the lumbar musculature observed by previous authors was confirmed; but no change in the relationship could be demonstrated as a result of strength gains. This suggested that the increased strength was attributable to increased motor unit activity rather than hypertrophy of muscle fibres.

Lenman (63) was able to demonstrate that patients with weak muscles resulting from neurological or muscular disease had a steeper slope (higher voltage for a similar tension) than stronger healthy subjects.

If a muscle is fatigued by a prolonged isometric contraction or isotonic exercises, it has been found by Edwards and Lippold (36) that more electrical activity is associated with a given tension in the fatigued state. This was supported by work done by Lloyd et al (70) who suggested that, in the final portion of contraction where EMG's are greatest, there is a localized fatigue of active muscle where additional effort is needed to maintain the specific tension. Lloyd (69) also obtained amplitude increases as ten male volunteers maintained isometric contractions involving elbow flexors as long as possible at 30, 50, and 70 per cent of maximal contraction.

The integrated electrical activity of the lumbar erectores spinae was investigated in eight male subjects by

Chapman and Troup (18) while maintaining steady pulling forces at 30 per cent of maximum for four minutes. There was a fall in the output of electrical activity between the beginning of pull and after three minutes of the order of 50 per cent. Towards the end of pull it increased; but only in ten out of 55 observations did the final electrical output exceed the initial level.

Cardiovascular Response to Lifting (Heart Rate and Blood Pressure)

In sustained contractions, the mass of skeletal muscle involved seems within an extreme range unimportant with regard to the cardiovascular response. The relevant factor seems to be the fraction of maximal isometric tension exerted by any muscle group (65). In a study by Lind (64), a 30 per cent of maximum contraction of small forearm muscles in hand-grip strength testing had the same effect on heart rate and blood pressure as 30 per cent of maximum contractions in the large leg muscles flexing the hip. Cardiovascularly speaking, the simultaneous contractions of two groups of muscles at the same proportional tension, according to Lind (64,66), do not have an additive effect. In fact the response is the same as if only one group had contracted. DeVries (33) has contradicted this by concluding that the heart rate response is determined almost entirely by the total mass of muscle involved during crawling, walking, and cycling.

(1) Studies Involving Loads and Lifting

Lind and McNicol (65) examined the cardiovascular responses of holding, by hand, weights equivalent to the load exerted through each handle of a loaded stretcher; and the benefits of holding these loads suspended from a shoulder harness. Tests were also carried out while actually carrying a man on a stretcher, by hand and by shoulder harness, as well as the effects of holding graded weights in one or both hands to simulate holding and carrying of parcels. When the subjects stood, arms dependent, in support of 20 kilograms for two and a half minutes, in the right or left hand or both, the blood pressure and heart rate rose progressively. When the weights were released, the blood pressure and heart rate quickly returned to resting values. When 40 kilograms was held in the hands (20 kilograms in each hand) for two and a half minutes, the blood pressure and heart rate rose to higher levels than when 20 kilograms was held just in the right hand. Use of a 40 kilogram shoulder harness worn for fifteen minutes, caused the blood pressure and heart rate to rise initially by 23 mm. Hg. and 6 bpm. respectively; but this steady state was maintained for the fifteen minutes - suggesting that the harness technique was much less fatiguing. In the live situation stretcher bearers, walking at 2 m.p.h. in support of 82 kilograms (stretcher + subject), were subject to sharp and steady rises in blood pressure and heart rate. At the three minute mark, these values were 143 mm. Hg. and 145 bpm. respectively accompanied by fatigue. Use of

the shoulder harness in the same situation produced values of 96 mm. Hg. and 125 bpm. at the three minute mark. Corresponding values after fifteen minutes were 98 mm. Hg. and 138 bpm. without undue fatigue. The graded weights aspect showed that holding 5 or 10 kilograms in the right hand for five minutes induced a quick rise in heart rate and blood pressure, but also a soon-reached steady state. A weight of 20 kilograms caused a steady rise in both parameters with no steady state and rapid fatigue. Forty and 80 kilograms using the harness could be tolerated without fatigue for fifteen minutes - the blood pressure and heart rate having reached a steady state in a few minutes. The critical point seemed to be between 80 and 120 kilograms where the two variables rose steadily throughout and fatigue occurred after three minutes. The authors concluded that the important factor is the proportion of tension exerted by a given group of muscles, and that a distinction can be drawn between sustained contractions producing fatigue and those that do not.

A study involving the biceps, triceps, brachialis, and brachioradialis done by Carlsoo and Guharay (16) demonstrated that when the arms were straight and supported loads up to 15 kilograms without any activity in these muscles (i.e., load hanging on the ligaments); the static work performed could be continued for fifteen minutes with the same blood supply as the non-loaded situation. However, as soon as the muscles were active, the need of oxygen demanded a higher blood supply causing a rise in heart rate and blood pressure.

Knuttgen et al (60) found this to be the case in bicycle ergometer tests where the relationships between heart rate and oxygen consumption were very similar at various muscle tensions at similar oxygen consumptions. However the heart rates in eccentric work seemed to exceed those obtained in concentric work at the same oxygen consumption.

Datta et al (24) investigated the cardiovascular effects of stepping up and down a 25 centimeter-high stool (step test) twenty times a minute for ten minutes while supporting loads of 0, 10, 15, and 20 kilograms. The mean peak heart rates for this exercise were 134.6, 153.8, 159.0, and 165.3 respectively. These high values are in accordance with the literature for dynamic work (64,65,66,67,75).

Shvartz (87) compared the effects of isotonic and isometric exercises involving the military press on twelve subjects averaging twenty-one years of age. The isotonic exercises were performed for 45 seconds at 50 per cent maximum resistance, while the isometric exercises were done for the same duration at 1/2 and 2/3 maximum resistance. Results indicated that isometric exercise performed for 45 seconds at 1/2 maximum resistance could stimulate the heart rate to the same extent that isotonic exercise could, using the same intensity and duration. The author also found that increasing the isometric load resulted in a proportionate increase in heart rate; and that increasing this load to maximum resulted in a near two-fold increase in heart rate immediately after exercise.

In analyzing a standard Olympic lift of 167.5 kilograms, Corser et al (23) traced the heart rate response throughout and after the lift. Heart rate changes from beat to beat were markedly constant during the lift; and full elevation of the heart rate only occurred after the exercise. The total exercise took 33 seconds.

Bartels et al (6) discovered that a 10 second isometric pull on a dynamometer at 60 per cent of maximum caused the heart rate to rise slightly during the exercise and sharply in the few seconds following the exercise. It had returned almost to resting level within 20 to 30 seconds following exercise.

Cathcart et al (17) found an increase in heart rate following the cessation of isometric work, and demonstrated that diastolic blood pressure was more markedly raised than systolic pressure.

Thompson (98) found that isometric work caused a pronounced rise in systolic and diastolic blood pressure with the latter returning to resting levels in about 30 seconds.

Rasch (81), and Rasch and Morehouse (83), on the other hand, found that having a subject hold a weight equal to 2/3 of his maximal strength for 15 seconds caused an increase in systolic and a decrease in diastolic blood pressure.

Exercise and Training for Lifting and Backstrength

(1) Strength Studies

Research studies involving training have been mainly

concerned with elbow flexion and extension. Singh and Karpovich (96) found that training the forearm extensors maximally and eccentrically four times a week for eight weeks through a range of 40 to 150 degrees produced mean increases of 42.8 per cent for concentric strength, 22.9 per cent for eccentric strength, and 40.3 per cent for isometric strength. The corresponding increases for the antagonists or flexors were 30.9, 16.7, and 26.4 per cent respectively. Training of back muscles and back strength has not received as extensive attention.

Delorme (29) employed a progressive resistance type of training where hyperextension exercises were performed on a table with increasing loads applied to a weight pan on the subject's back. The program, carried out on polio patients, consisted of seven to ten sets of 10 RM weight (where RM = the maximum weight that can be lifted through the range of movement). The author retested each week to determine a new strength score (1 RM) and 10 RM value for training. Results showed that strength improved significantly (in some cases up to 300 per cent of initial values).

Asmussen (2) studied the effects of static and dynamic training on back muscle strength, and found that each produced approximately the same degree of improvement. However, the author suggested that dynamic training might not be as efficient because it does not usually allow sufficient time for muscles to reach their maximum tension.

Berger (8) tested the static and dynamic strength of

the lower back muscles before and after twelve weeks of training on seventy-eight male students at the University of Illinois. Static strength was measured by a back-pull machine, and dynamic strength by means of a back hyperextension lift. The isometric group, training on the back-pull machine with three sets of 6 second maximal contractions, improved their static strength mean by 11.13 pounds and their dynamic strength mean by 9.43 pounds. The isotonic group performed eight to twelve maximal back hyperextension repetitions and increased 7.3 pounds statically, but as much as 21.15 pounds dynamically. All increases were significant. The author concluded that static strength was improved more by static training, and dynamic strength more by dynamic training. Rasch and Morehouse (83) found similar results on elbow flexion and isometric arm pressing.

In a similar study by Berger (9), involving the bench-press lift, nine groups were tested before and after twelve weeks of progressive resistance exercise. Each group trained differently in number of repetitions per set. Resistances employed were 2 RM, 4 RM, 6 RM, 8 RM, 10 RM, and 12 RM for one set. Group means for these resistances after training were 146.56, 154.52, 151.96, 155.69, 148.29, and 149.74 pounds respectively. The author concluded that the optimum number of repetitions occurred between three and nine. The corresponding number of repetitions for isometric training has been suggested by Gardner (47) as one 6 second contraction at 2/3 maximum; by Dennison et al (31) as one maximal

6 second contraction; and by Berger (8) as two maximal 6 second contractions.

One 6 second contraction was used by Baley (5) on 104 students at the University of Connecticut who participated in a four week program of isometric exercises done with a nylon belt. When all groups were treated together, a mean gain of 57 pounds was made in the back-lift. This was significant at the 0.0005 level. The high-fitness class made a greater improvement. Classes which did only isometric exercises for 1/2 hour three times per week for four and a half weeks made greater mean gains than did classes which met for sixty minutes twice a week for four and a half weeks and did stretching exercises and running in addition to isometric exercises. In both the initial and final back-lift means, the low fitness classes had the lowest scores, and the highest fitness classes had the highest scores.

Taylor (96) found that wrestlers participating in a twelve week muscular endurance-cardiovascular training regimen exhibited significantly greater gains in back and total body strength than those participating in weight lifting at 70 per cent of initial strength for a similar twelve weeks.

(2) Training and EMG's

Although all subjects gained in maximal back-pull strength after submaximal training at 10, 20, and 30 per cent of maximal pulls twice daily for four days, and maximal training twice daily for one week; Chapman and Troup (19)

noted no change in the relationship between the integrated EMG's and external forces produced as a result of strength gains (mean gain being 14.5 kilograms). Thus no change in the 'efficiency' as defined by DeVries (32) could be shown for the lumbar musculature. It might be inferred that the increase in strength was due solely to increases in motor unit activity, and that no hypertrophy occurred.

Similar results were obtained by Chapman and Troup (18) over a period of 33 days. No changes in the integrated EMG pattern accompanied mean increases in strength of 13.3 kilograms.

(3) Cardiovascular

In sustained isometric contractions above 15 per cent of maximum, the increase in heart rate has been found to be modest; and at fatigue it is uncommon to find values over 120 beats per minute, although increases in blood pressure may be dramatic (64). Falls (41) states that even strong and long lasting isometric contractions put only very slight demands on the cardio-respiratory and vascular systems, and are therefore a very poor training form for endurance.

However, in dynamic weight lifting the load on the muscles is seldom maximal, but it will increase the isometric strength of the muscles undergoing training in proportion to the loads they have been opposing. At the same time it will increase the capacity for performing the training exercises and the endurance in performing them (41). Corser *et al* (23)

did not obtain a full elevation of heart rate to maximum values until after the lift was completed. Sharkey (85) has presented data indicating a need for a heart rate of 150 beats per minute before a training effect is elicited. The cardiovascular response to lifting was outlined in a separate section earlier in this chapter. However, little is known of its response as a result of lifting and back strength training.

Electrogoniometry and Lifting

Karpovich and Karpovich (56) have developed an electrogoniometer to study joint movement. Basically the electrogoniometer consists of a round rheostat with two shafts attached. The electrogoniometer is attached to the joint while the rheostat rests on the joint itself. A more detailed description of the electrogoniometer is given in Chapter III.

Klissouras and Karpovich (59), in their study of jumping events used an electrogoniometer on the hip joint. Singh and Ashton (89) adapted this technique in their study of back-lift strength to determine variations in hip angle.

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CHAPTER III

METHODS AND PROCEDURES

Subjects

Forty male physical education student volunteers in attendance at the University of Alberta were used as subjects in a pretest and post test situation with a five week training program between. The subjects were healthy and had no history of lower back problems. The subjects ranged in age from 21 to 40 years.

Experimental Design

In the pretest, each subject was ranked according to the total strength score (isometric + concentric + eccentric) exerted and randomly blocked into one of three different training groups or the control group (ten in each group). The pretest involved one maximal isometric back-lift at a hip angle of 160 degrees; one maximal concentric back-lift through a hip angle range of 150 to 170 degrees; and one maximal eccentric back-lift through a range of 170 to 150 degrees. To complete the isometric test set, one maximal hip flexion test at a hip angle of 160 degrees was performed using a modification of Clarke's trunk flexion test (1). Thus the pretest entailed an isometric, concentrit, and eccentric test set.

After the five week training period, the post test involved one isometric lift at the original pretest maximum (isometric test set for efficiency) and one at the new maximum; one new maximal concentric and eccentric back-lift through the same ranges as in the pretest. To complete the isometric test set, one new maximal isometric hip flexion test at 160 degrees was performed. Thus the post test consisted of an isometric, concentric, eccentric, and isometric test set for efficiency. In the concentric and eccentric test sets, analyses were made at the 160 degree hip angle mark as in the isometric test sets (i.e., 20 degrees from the vertical).

All strength, electromyographical and heart rate measures were recorded throughout each lifting test set as well as hip angle. Curvature measures were recorded only in the isometric test set and the isometric test set for efficiency. A one minute rest interval was allowed between each test set at pretest and post test. To prevent undue fatigue, one trial was allowed for each test set. All test sets were administered in random order before and after training.

Anthropometrical Data

The following anthropometrical data was collected from each subject: age (months); height (inches), and weight (pounds).

Procedures for Administering the Tests

Four test sets were administered to each subject.

Isometric Test Set. Each subject executed a maximal isometric back-lift at a hip angle of 160 degrees and a maximal isometric hip flexion test at the same angle at pretest and post test. The strength test involved use of the back-lift technique and experimental back-lift dynamometer (8,9).

Concentric Test Set. The maximal concentric back-lift strength through a hip angle range of 150 to 170 degrees was recorded for each subject at pre and post test as the cable released at 2.25 inches per second (2).

Eccentric Test Set. The maximal eccentric back-lift force through a hip angle range of 170 to 150 degrees was carried out by each subject at pre and post test as the cable lowered at 2.25 inches per second. The cable pulled the subject down as he tried to extend maximally and continually.

Isometric Test Set for Efficiency. This test set was completed at post test and required each subject to perform an isometric back-lift equal in magnitude to his pretest value. In this way any changes in efficiency, with regard to lumbar curvature, back muscle electrical activity, and heart rate, were observed.

In the isometric test set and the isometric test set for efficiency, each subject's lumbar spinal curvature was calculated at peak pull from a lateral photograph taken with a Polaroid Land Camera (Model 900) at a distance of five feet from the subject's lumbar vertebrae and at the same height.

Golf tees, painted black and tipped white, were adhered over the spinous processes of L1 to L5 by means of Beckman adhesive collar tapes (Figure 1) after the spinous process positions had been established by palpation according to Ellis (3:351). A dark background facilitated clear readings of the tips of the tees. Resultant lumbar curvature was read as the angle subtended by the lines perpendicular to the L1 and L5 points on the curve derived from joining the five tips in each photograph.

During all test sets, muscle action potentials of the erectores spinae were taken at one and two inches from the spine on the right side at a level between L4 and L5 using surface electrodes 8 millimeters in diameter as recommended by O'Connell and Gardner (7). The distance between the two electrodes, held in place by a thin rubber belt, was 1 1/2 centimeters, with the third electrode (ground) being fastened to the right ankle. It was hoped that this paramedial spacing would yield an overall picture of the erectores spinae branches from medial to lateral (10).

In all test sets, heart rate was recorded during and immediately following each contraction for ten seconds by means of surface electrodes.

An electrogoniometer was attached with adhesive tape to the left hip of each subject for all test sets in order to record the hip angle. The electrogoniometer was placed on the lateral side of the left hip so that the rheostat rested on the midpoint of the greater trochanter of the femur

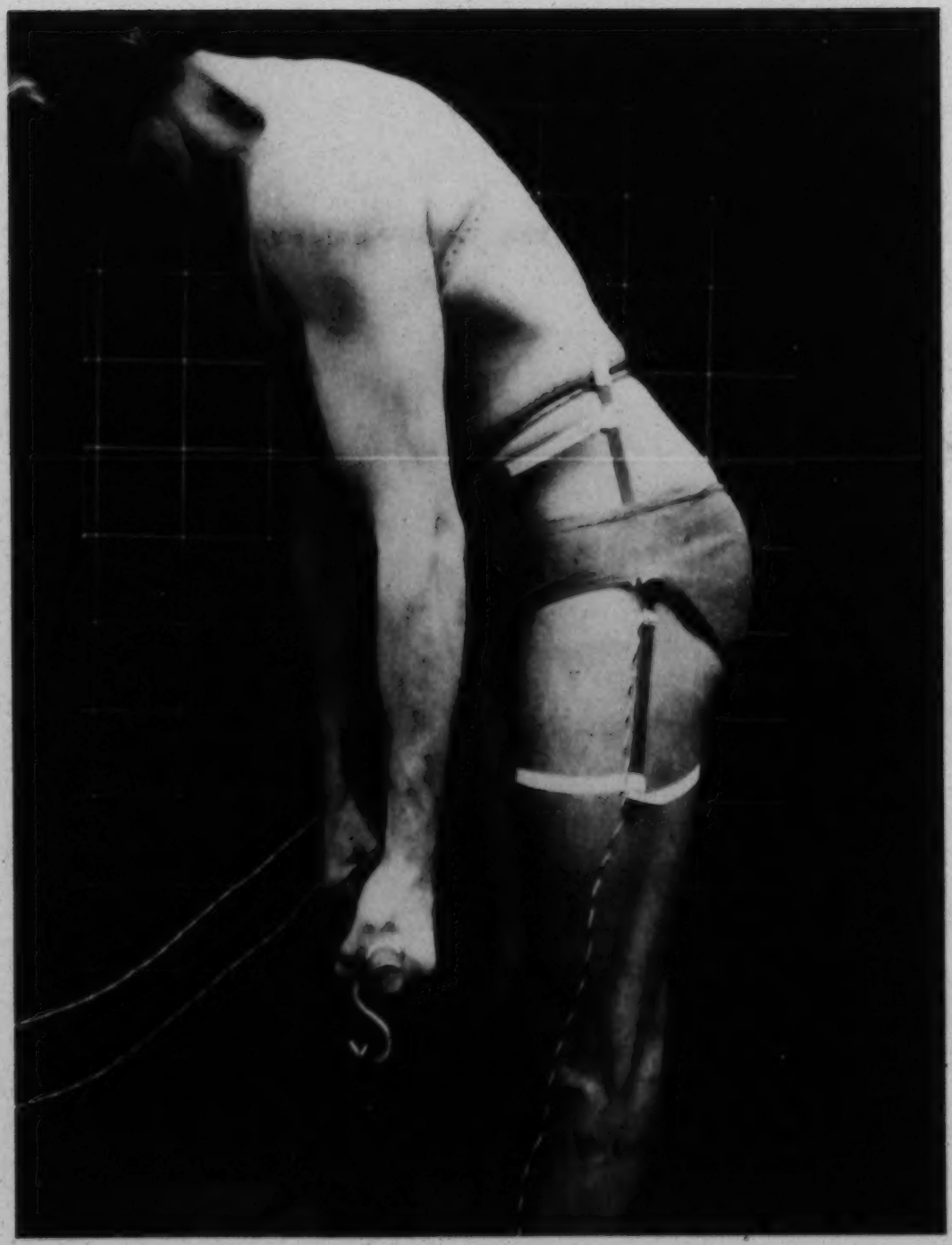

Figure 1. Method of Measuring Lumbar Spinal Curvature.

with shafts connecting with the iliac crest and the midpoint of the lateral epicondyle (6).

In all the test sets, the feet were placed so that the malleoli of the ankle joints were opposite the base of the cable and six inches apart (Figure 2). The subjects, employing a mixed grip, were asked to lift straight up in the isometric, concentric, and isometric test set for efficiency; and attempted to extend their backs maximally while keeping their legs straight. The situation was similar in the eccentric test set, and subjects were asked to resist continually and maximally as the cable pulled them down. All test set contractions lasted approximately three seconds.

Training

Subjects in Group I underwent maximal isometric back-lift training at a hip angle of 160 degrees using the experimental back-lift dynamometer.

Group II trained maximally and concentrically, back-lifting through a hip angle range of 150 to 170 degrees using the same dynamometer.

Group III participated in maximal eccentric back-lift training through a hip angle range of 170 to 150 degrees.

The fourth group acted as a control, involved only in the pretest and post test situation.

Each training subject performed three days per week (MWF) for five weeks. Three maximal trials with a one minute rest between were given each testing day. The 'shout method'

Figure 2. Experimental Apparatus and Subject

was used for encouragement.

Experimental Apparatus

Back-Lift Dynamometer. The experimental back-lift dynamometer is a multipurpose device which can be used for isometric, concentric, and eccentric strength testing and training (2,8,9). It consisted of an electric motor connected to a double-acting hydraulic cylinder from which a cable passed over two ball-bearing pulleys and emerged at a point directly between the subject's feet and in front of him. The cable was connected to a load cell, connected by means of a chain link to the bar, which was grasped using a mixed grip. The entire system could be maintained (isometric), or raised or lowered for each subject (concentric and eccentric respectively) by means of the hydraulic mechanism. Figure 2 illustrates the dynamometer, subject, and other apparatus used in this study.

Lumbar Spinal Curvature Cinematography. Five golf tees were painted black and tipped with white paint. They were attached on end, flat end to the skin, over the spinous processes of the five lumbar vertebrae by means of Beckman electrode tape collars when the subjects had assumed the 160 degree hip angle. The heads of the tees had been previously filed so that the circular tapes fitted over them.

An Electric Eye Polaroid Land Camera (Model 900), mounted on a tripod, was situated five feet from the side of the subject's lumbar vertebrae and at the same height. A

dark sheet of plyboard was placed behind each subject (opposite side of the subject to the camera) enabled the white tips of the tees to show vividly on the photographs. In each photograph, the tips were joined producing approximate lumbar curvature. Perpendiculars to this curve at L1 and L5 were drawn on the photographs and extrapolated to the point where they joined giving the total angle change in degrees.

Honeywell Recorder. The Honeywell electronic medical system consisted of a Model 1912 Visicorder for recording physiological phenomena. This system included a Model 8011 multichannel oscilloscope for data display. A sample recording from this study is shown in Figure 3.

Load Cell. The load cell used was a 1,000 pound capacity load cell, Model UG31 tension type from BLH Electronics. Signals from the load cell were recorded on an Accudata 113 biomedical amplifier of the Honeywell recorder which was calibrated to move 1 millimeter for every 5 pounds of tension on the load cell (5).

Electrogoniometer. The electrogoniometer consisted of a rheostat with two plastic shafts. The rheostat portion was placed over the midpoint of the greater trochanter of the femur with the two shafts connecting with the iliac crest and the midpoint of the lateral epicondyle. The electrogoniometer was connected by a wire to a meter, which in turn was connected to another channel of the recorder. Power for the electrogoniometer was supplied by two 9-volt

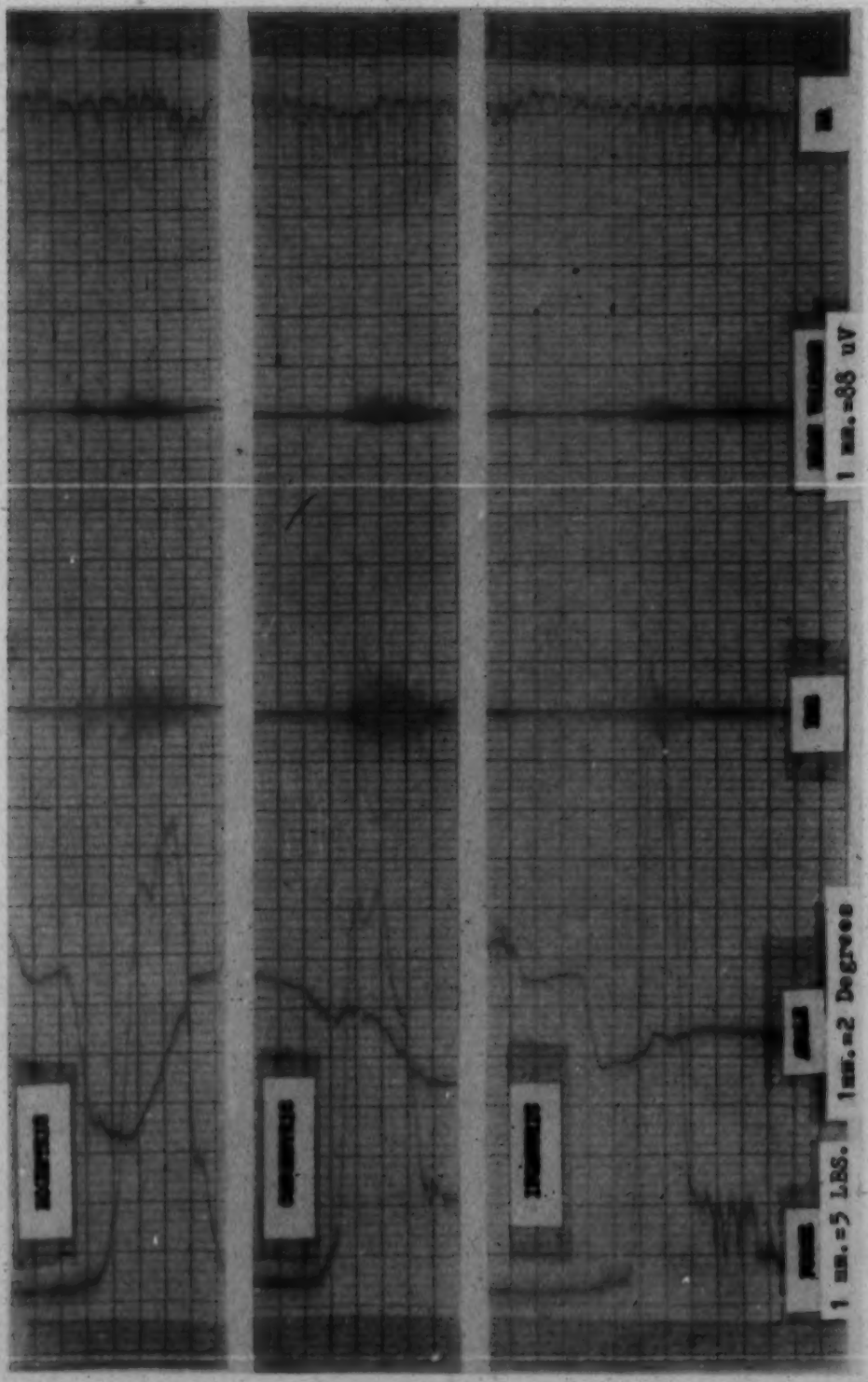

Figure 3. Sample Recording for Three Types of Back-Lift Strength

transister batteries. For calibration, a protractor was attached to the electrogoniometer so that one shaft was immobilized while the other was free to move causing a change in angle. The electrogoniometer was calibrated so that each degree of change produced a deflection of 1 millimeter on the Honeywell recorder.

Electromyograms. Two metal surface electrodes, 8 millimeters wide and one inch long, were attached paramedially at one and two inches from the spine on the right side at a level between L4 and L5, with the distance between them being 1 1/2 centimeters approximately. The electrodes were coated with electrode jelly and inserted into their respective places underneath a rubber belt running snugly around the subject at the specified level. Another similar electrode was attached with adhesive tape to the right ankle of each subject. Leads were connected to an Accudata 135 component of the recorder, and electromyographical spikes were simultaneously rectified by an Accudata 136 physiological integrator to give the mean peak voltage. A calibration, 1 millivolt, spike, was registered on the Honeywell recorder as a frame of reference for each subject (5). All readings were recorded in microvolts.

Heart Rate. Three metal surface electrodes, 3/4" by one inch, were attached underneath a rubber belt fastened snugly and horizontally around the subject just below the nipples. Two electrodes on the front of the subject (one on each side) and one on the right side at the back acting as a

ground were connected by leads to another Accudata 135 channel of the recorder. With the paper speed at 2.5 centimeters per second, heart rate in beats per minute was easily attainable.

Clarke's Table for Cable-Tension Tests. The table, approximately 6'6" long, 2'9" wide, and 2'6" high, had a twenty by seven inch cut lengthwise in the centre of it beginning ten inches from one end so as to permit attachment of the pulling assembly below the subject. Each subject assumed a supine position, knees fully extended, arms folded across the chest. The subject then flexed at the hips to make an angle of 160 degrees. A trunk strap was placed around the chest and was connected to a 5/32" steel cable, which was attached to the appropriate hook for pulling. As the subject flexed maximally at the hips, a cable tensiometer (Pacific Scientific Co., No-01-06) with a number two riser was applied to the cable giving its tension. A study on five trials at loads from 60 to 250 pounds in 10 pound increments prior to the experiment gave a reliability coefficient of .99 for the cable tensiometer (11:124-132).

Calibration of the Apparatus

The load cell was calibrated by comparing the indicated output deflections with known weights added in 10 pound intervals. Linearity of the load cell measurements was confirmed. The Honeywell recorder was calibrated according to the Honeywell Electronic Medical System Manual.

Statistical Treatment

Reliability coefficients using analysis of variance and standard errors were computed where possible. The significance of the differences among post test group means of each variable in each test set was computed using the analysis of covariance technique (11:581-8). t-tests between pre and post test means were performed on each group in each test set for each variable (11:39-43). A correlation matrix was also determined for the variables in each test set using pretest means (4:105-130). Where significance occurred, simple main effects on groups were analyzed by the Newman-Keuls test (11:80-85).

Pilot Study

A pilot study was carried out on three University of Alberta students to check functioning of the respective recording channels and to evaluate the cinematographical technique in assessing lumbar curvature.

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CHAPTER IV

RESULTS AND DISCUSSION

Analysis of Data

The analysis of data is presented in the following order: reliability estimates for variables measured and standard errors of measurement; pre and post test means for each group on each variable in the isometric test set; analysis of covariance on post test treatment groups for each isometric test set variable; t-tests between pretest and post test means for each group on each isometric test set variable; and a pretest correlation matrix for variables contained in the isometric test set. The means, analysis of covariance, t-tests, and correlation matrices were then repeated for the concentric and eccentric test sets, and the isometric test set for efficiency.

Reliabilities. The following reliability coefficients on maximal back-lift strength, electromyographical mean peak voltages of the lumbar erectores spinae, and heart rate measures were determined on all subjects during pretest. These coefficients were derived by analysis of variance to estimate the reliability of measurements over isometric, concentric, and eccentric test sets (32:124-131). For purposes of convenience, the word 'electromyogram' will be noted as EMG.

TABLE I

RELIABILITY COEFFICIENTS

Variable	Reliability Coefficients
Back-Lift Strength	0.83
EMG (Mean Peak Voltage)	0.92
Heart Rate	0.92

The reliability coefficients are test-retest correlations and make no indications as to the precision of an individual's score. The corresponding reliabilities for an individual's score on each of these three variables are given in Table II.

TABLE II

RELIABILITY COEFFICIENTS

Variable	Reliability Coefficients
Back-Lift Strength	0.62
EMG (Mean Peak Voltage)	0.80
Heart Rate	0.79

The standard error of measurement for each variable was computed according to Thorndike and Hagen (29:183) by means of employing the reliability coefficients from Table I and the standard deviations from Table IV. Table III shows

the standard error of measurement for each of the three variables.

TABLE III

STANDARD ERROR OF MEASUREMENT - SUMMARY

Variable	Sm.
Back-Lift Strength	29.22 lbs.
EMG (Mean Peak Voltage)	54.10 uV
Heart Rate	4.42 bpm

It can be seen from Table III that scores on strength could be expected to vary in approximately sixty-eight per cent of the cases by ± 29.22 pounds, on EMG mean peak voltage by ± 54.10 uV, and on heart rate by ± 4.42 beats per minute.

Table IV displays the pretest means of the isometric, concentric, and eccentric test sets for each variable measured for all subjects and is based on the raw data shown in Appendix A. The variables, lumbar curvature and trunk flexion strength were only measured as part of the isometric test set at pretest. As there was only one score for each person on each of these two variables, it was impossible to calculate their reliability coefficients and standard errors of measurement.

In order to approximate these two reliabilities an analysis of variance with repeated measures (pretest vs.

TABLE IV

MEANS OF VARIABLES BY TEST SETS (PRETEST)

	Variable				
	Back-Lift Strength	EMG Mean Peak Voltage	Heart Rate	Lumbar Curvature	Trunk-Flexion Strength
Isometric Test Set	304.69	352.21	102.22	13.35	91.91
Concentric Test Set	222.94	389.73	107.63	--	--
Eccentric Test Set	315.31	384.81	98.10	--	--
General Means	280.98	375.58	102.65	13.35	91.91
General S.D.	71.26	193.21	15.79	6.43	33.36

post of isometric test set) was carried out using all subjects. The pretest-post test estimates for reliability for lumbar curvature and trunk flexion strength were 0.92 and 0.91 respectively. The corresponding estimates for an individual's score were 0.86 and 0.83. Due to the confounding of the treatment effects, it is likely that the reliability coefficients would have minimum values of 0.92 and 0.91 respectively.

The following analyses deal with the four test sets and their respective variables.

Isometric Test Set. Variables in this test set consisted of simultaneous measurements on maximal isometric back-lift strength, lumbar curvature, EMG mean peak voltage, heart rate and trunk flexion strength. To test treatment effects on each variable, an analysis of covariance was carried out on group post test means using pretest results as the covariate. The pre and post test means for each group on each of the five variables are found in Table V.

The significance of the observed differences among post test group means on maximal isometric back-lift strength in Table V was tested by analysis of covariance. The results are displayed in Table VI.

The adjusted F value for groups, using pretest results as the covariate, was significant at the .05 level of confidence.

In order to find out where the difference(s) occurred, the Newman-Keuls test on ordered and adjusted post test group

TABLE V

MEANS OF VARIABLES AT PRE AND POST TEST - ISOMETRIC TEST SET

Variables	Groups (N=10)	Pretest	Post-Test
Isometric Back-Lift Strength (lbs.)	I	312.00	396.00
	II	321.00	376.95
	III	292.75	380.00
	IV	293.00	323.50
Lumbar Curvature (degrees)	I	14.55	12.55
	II	12.75	11.95
	III	14.10	13.50
	IV	12.00	12.00
EMG Mean Peak Voltage (uV)	I	353.78	434.42
	II	328.69	425.26
	III	292.13	413.95
	IV	434.24	425.44
Heart Rate (bpm)	I	102.90	101.60
	II	102.00	97.80
	III	108.00	102.00
	IV	96.00	91.20
Isometric Trunk-Flexion Strength (lbs.)	I	91.65	109.95
	II	92.90	101.65
	III	98.95	98.35
	IV	84.15	82.15

TABLE VI

ANALYSIS OF COVARIANCE - SUMMARY
MAXIMAL ISOMETRIC BACK-LIFT STRENGTH

Source	df	Mean Squares	Adjusted F	p
Groups	3	8155.207	4.221	0.012
Within	35	1932.071		
RSQ = 0.308				

means was used according to Winer (32:592). The results of tests on differences between pairs of post test adjusted means are shown in Table VII.

Table VII demonstrates that, on maximal isometric back-lift strength, each of the three training groups had significantly higher scores after training than the control group.

Analysis of covariance was repeated on groups for lumbar spinal curvature (see Table V) and is found in Table VIII.

The adjusted F value for groups was not significant.

Thus there was no significant difference among group adjusted post test means of lumbar spinal curvature when pretest curvature results were used as the covariate.

A similar analysis of covariance was carried out to test the significance of the observed differences among post test group means of mean peak voltages from lumbar erectores spinae electromyograms. As seen from Table IX, tha adjusted F value for groups was not significant.

TABLE VII

TESTS ON DIFFERENCES BETWEEN PAIRS OF MEANS
FOR MAXIMAL ISOMETRIC BACK-LIFT STRENGTH

Groups		IV	II	III	I
	Means	328.631	369.789	385.240	392.790
IV	328.631	--	41.158	56.609	64.159
II	369.789		--	15.451	23.001
III	385.240			--	7.550
I	392.790				

Truncated Range r	2	3	4
q.99 (r,35)	3.855	4.41	4.75
$\sqrt{MS'\ error\ (effective)/n}$ q.99 (r,35)	53.927	62.125	66.447
q.95 (r,35)	2.875	3.465	3.815
$\sqrt{MS'\ error\ (effective)/n}$ q.95 (r,35)	40.218	48.472	53.368

	IV	II	III	I
IV		*	*	*
II			-	-
III				-
I				

* Note: * = .05 level of significance.

TABLE VIII

ANALYSIS OF COVARIANCE - SUMMARY
LUMBAR SPINAL CURVATURE

Source	df	Mean Squares	Adjusted F	p
Groups	3	4.187	0.465	0.71
Within	35	9.012		
RSQ = 0.752				

TABLE IX

ANALYSIS OF COVARIANCE - SUMMARY
EMG MEAN PEAK VOLTAGE

Source	df	Mean Squares	Adjusted F	p
Groups	3	20016.145	0.933	0.44
Within	35	21445.969		
RSQ = 0.483				

The corresponding analysis of covariance on groups for heart rate using pretest heart rate scores as the covariate is found in Table X. Again, the adjusted F value for groups was not significant.

Analysis of covariance was then performed on adjusted post test group means for maximal isometric trunk-flexion strength. The results are shown in Table XI.

TABLE X

ANALYSIS OF COVARIANCE - SUMMARY
HEART RATE

Source	df	Mean Squares	Adjusted F	p
Groups	3	56.996	.364	0.78
Within	35	156.700		
RSQ = 0.334				

TABLE XI

ANALYSIS OF COVARIANCE - SUMMARY
MAXIMAL ISOMETRIC TRUNK-FLEXION STRENGTH

Source	df	Mean Squares	Adjusted F	p
Groups	3	899.367	2.401	0.08
Within	35	374.618		
RSQ = 0.728				

The F value for adjusted post test group means was not significant.

In order to look at training effects, t-tests (correlated samples) between pre and post test measurements, were carried out on each group for each of the five variables measured in the isometric test set. These t-test values for means and accompanying probabilities of t's for any differ-

ences between pre and post test means of Table V are displayed in Table XII.

TABLE XII

t-TESTS AND PROBABILITIES - ISOMETRIC TEST SET BETWEEN PRE AND POST TEST

Variables	Groups (N=10)	t-Test Values for Means	Probabilities
Isometric Back-Lift Strength (lbs.)	I	-4.260*	0.002
	II	-3.652	0.005
	III	-3.937	0.003
	IV	-2.274	0.05
Lumbar Curvature (degrees)	I	1.306	0.22
	II	0.825	0.43
	III	0.660	0.53
	IV	0.000	1.00
EMG Mean Peak Voltage (uV)	I	-2.307	0.05
	II	-3.105	0.01
	III	-1.644	0.14
	IV	0.284	0.78
Heart Rate (bpm)	I	0.271	0.79
	II	0.805	0.44
	III	1.732	0.12
	IV	1.714	0.12
Trunk-Flexion Strength (lbs.)	I	-4.465	0.002
	II	-0.927	0.38
	III	0.114	0.91
	IV	0.504	0.63

Note: *Negative sign used when pretest mean minus post test mean is negative

As can be seen from Table XII, all groups increased in maximal isometric back-lift strength (the three training groups beyond the .01 level of confidence). Lumbar spinal curvature was less after training for groups I, II, and III; and equal to the pretest mean for the control group. EMG mean peak voltage readings were seen to parallel the strength increases at post test except for the control group whose mean had dropped slightly. Heart rate was lower for all groups after training; however not significantly lower. The only significant training increase in isometric trunk flexion strength occurred with group I (the isometric trainfng group).

A correlation matrix, using the Pearson Product Moment Correlation Coefficient between pairs of variables, was calculated for the five variables measured in the isometric test set at pretest. These values, as well as the probabilities of t-values associated with the correlation coefficients, are presented in Table XIII.

On the basis of Table XIII, there was a significant relationship between maximal isometric back-lift strength and heart rate and between maximal isometric back-lift strength and trunk-flexion strength; between lumbar curvature and heart rate; and between heart rate and trunk-flexion strength.

Concentric Test Set. The variables in this test set consisted of maximal concentric back-lift strength, EMG mean peak voltage, and heart rate. To test for treatment effects on each variable, an analysis of covariance was carried out

TABLE XIII

CORRELATION MATRIX AND PROBABILITIES - ISOMETRIC TEST SET

Variables	Isometric Back-Lift Strength	Lumbar Curvature	EMG Mean Peak Voltage	Heart Rate	Trunk-Flexion Strength
Isometric Back-Lift Strength	1.00	0.17 (p=.29)	0.24 (p=.14)	0.48 (p=.002)	0.35 (p=.03)
Lumbar Curvature		1.00	0.08 (p=.62)	0.42 (p=.007)	-0.15 (p=.37)
EMG Mean Peak Voltage			1.00	0.14 (p=.40)	0.004 (p=.98)
Heart Rate				1.00	0.37 (p=.02)
Trunk-Flexion Strength					1.00

on group post test means using pretest results as the covariate. The pre and post test means for each group on each of these three variables are seen in Table XIV.

TABLE XIV

MEANS OF VARIABLES AT PRE AND POST TEST - CONCENTRIC TEST SET

Variables	Groups (N=10)	Pretest	Post-Test
Concentric Back-	I	221.25	308.00
Lift Strength (lbs.)	II	217.50	326.00
	III	222.75	326.00
	IV	230.25	256.00
EMG Mean Peak	I	361.28	443.04
Voltage (uV)	II	411.01	579.74
	III	270.14	502.89
	IV	516.46	475.81
Heart Rate (bpm)	I	105.60	102.60
	II	106.50	105.60
	III	116.40	105.60
	IV	102.00	94.20

The significance of the observed differences among post test group means on maximal concentric back-lift strength in Table XIV was tested by analysis of covariance. Results are given in Table XV.

The adjusted F value for groups using pretest results as the covariate was significant at the .05 level of confidence.

TABLE XV

ANALYSIS OF COVARIANCE - SUMMARY
MAXIMAL CONCENTRIC BACK-LIFT STRENGTH

Source	df	Mean Squares	Adjusted F	p
Groups	3	12280.102	3.619	0.02
Within	35	3392.636		
RSQ = 0.234				

The Newman-Keuls test was then carried out on ordered and adjusted post test group means according to Winer (32: 592). Results of these tests on differences between respective pairs of adjusted means are found in Table XVI.

Thus, on maximal concentric back-lift strength, each of the three training groups had significantly higher scores after training than did group IV, the control group.

A similar analysis of covariance on lumbar erectores spinae mean peak voltage from electromyograms (see Table XIV) produced the results found in Table XVII.

Here, the adjusted F value for groups was also significant at the .05 level of confidence.

Results of the Newman-Keuls test on ordered and adjusted post test group means as per Winer (32:592) are displayed in Table XVIII. It is shown that the concentric and eccentric training groups had post test values which were significantly higher than the control group. The isometric group had post test results not significantly different from

TABLE XVI

TESTS ON DIFFERENCES BETWEEN PAIRS OF MEANS FOR MAXIMAL CONCENTRIC BACK-LIFT STRENGTH

Groups		IV	I	III	II
	Means	253.009	308.690	326.077	328.224
IV	253.009	--	55.681	73.068	75.215
I	308.690		--	17.387	19.534
III	326.077			--	2.147
II	328.224				

Truncated Range r	2	3	4
q.95 (r,35)	2.875	3.465	3.815
$\sqrt{MS' \text{ error (effective)}/n}$ q.95 (r,35)	52.990	63.864	70.315

	IV	I	III	II
IV		*	*	*
I			-	-
III				-
II				

Note: * = .05 level of significance.

TABLE XVII

ANALYSIS OF COVARIANCE - SUMMARY
EMG MEAN PEAK VOLTAGE

Source	df	Mean Squares	Adjusted F	p
Groups	3	77298.625	3.567	0.02
Within	[illegible]	21672.832		
RSQ = 0.538				

the other three groups on lumbar erectores spinae mean peak voltages during maximal concentric back-lifting. The group post test means from Table XIV on heart rate were also tested by analysis of covariance (see Table XIX). The adjusted F value for groups here was not significant.

In order to assess training effects, before and after training, t-tests for correlated samples were performed on each group for each of the three variables measured in the concentric test set. The t-test values for means and corresponding probabilities of t's for any differences between pre and post test means of Table XIV are presented in Table XX.

Table XX demonstrates that all four groups increased in maximal concentric back-lift strength - the training groups beyond the .01 level of confidence with the concentric group having the greatest increase. Mean peak voltages from lumbar erectores spinae EMG's also increased significantly for the three training groups. Heart rate immediately after

TABLE XVIII

TESTS ON DIFFERENCES BETWEEN PAIRS OF MEANS
FOR EMG MEAN PEAK VOLTAGE

Groups		IV	I	II	III
	Means	388.277	462.690	565.036	585.483
IV	388.277	--	74.413	176.759	197.206
I	462.690		--	102.346	122.793
II	565.036			--	20.447
III	585.483				--

Truncated Range r	2	3	4
q.95 (r,35)	2.875	3.465	3.815
$\sqrt{MS' \text{ error (effective)}/n}$ q.95 (r,35)	137.603	165.841	182.593

	IV	I	II	III
IV		-	*	*
I			-	-
II				-
III				

Note: * = .05 level of significance.

TABLE XIX

ANALYSIS OF COVARIANCE - SUMMARY
HEART RATE

Source	df	Mean Squares	Adjusted F	p
Groups	3	207.690	1.518	0.23
Within	35	136.830		
RSQ = 0.062				

TABLE XX

t-TESTS AND PROBABILITIES - CONCENTRIC TEST
SET BETWEEN PRE AND POST TEST

Variables	Groups (N=10)	t-Test Values for Means	Probabilities
Concentric Back-Lift	I	-3.964*	0.003
Strength (lbs.)	II	-5.867	0.000
	III	-3.399	0.008
	IV	-1.259	0.24
EMG Mean Peak	I	-2.635	0.03
Voltage (uV)	II	-2.253	0.05
	III	-4.182	0.002
	IV	1.508	0.17
Heart Rate (bpm)	I	0.478	0.64
	II	0.133	0.89
	III	2.176	0.06
	IV	2.751	0.02

* Negative sign used when pretest mean minus post test mean is negative.

contraction was lower at post test for each group, but only significantly lower for the control group who had not increased in their strength output.

The Pearson Product Moment Correlation Matrix between pairs of variables was also computed at pretest. These correlation coefficients as well as probabilities of t-values associated with the correlation coefficients are given in Table XXI.

TABLE XXI

CORRELATION MATRIX AND PROBABILITIES - CONCENTRIC TEST SET

Variables	Concentric Back-Lift Strength	EMG Mean Peak Voltage	Heart Rate
Concentric Back-Lift Strength	1.00	0.28 (p=.08)	0.34 (p=.03)
EMG Mean Peak Voltage		1.00	0.13 (p=.44)
Heart Rate			1.00

The only significant relationship found in Table XXI was between maximal concentric back-lift strength and heart rate.

Eccentric Test Set. The same three variables were contained in this test set; namely, maximal eccentric back-lift strength, EMG mean peak voltage, and heart rate. Treatment effects after training were tested by means of analysis of covariance. The pre and post test means for each group are

found in Table XXII.

TABLE XXII

MEANS OF VARIABLES AT PRE AND POST TEST - ECCENTRIC TEST SET

Variables	Groups (N=10)	Pretest	Post-Test
Eccentric Back-Lift Strength (lbs.)	I	314.00	354.50
	II	308.50	379.25
	III	324.00	421.50
	IV	314.75	334.75
EMG Mean Peak Voltage (uV)	I	364.60	399.84
	II	381.96	448.13
	III	296.94	513.35
	IV	495.75	446.54
Heart Rate (bpm)	I	101.40	98.40
	II	94.80	97.80
	III	105.60	102.60
	IV	90.60	87.60

Observed post test group mean differences on maximal eccentric back-lift strength in Table XXII were assessed by analysis of covariance with results being found in Table XXIII.

There was a significant difference beyond the .01 level of confidence between groups at post test.

The Newman-Keuls test on ordered and adjusted post test group means pin-pointed the differences found in Table XXIV.

From Table XXIV it can be seen that the eccentric group

TABLE XXIII

ANALYSIS OF COVARIANCE - SUMMARY
MAXIMAL ECCENTRIC BACK-LIFT STRENGTH

Source	df	Mean Squares	Adjusted F	p
Groups	3	12719.977	5.783	0.003
Within	35	2199.563		
RSQ = 0.385				

had significantly higher scores at post test than did the control group (p=.01) and the isometric group (p=.05).

Observed post test group mean differences on lumbar erectores spinae mean peak voltage (see Table XXII) during maximal concentric back-lifting were also tested by analysis of covariance. Results are displayed in Table XXV.

A significant difference between groups at post test had occurred at the .01 level of confidence.

Newman-Keuls results for ordered and adjusted post test group means are found in Table XXVI. The eccentric group had significantly higher values than did the control group at the .01 level; the isometric group and the concentric group both at the .05 level.

Analysis of covariance on heart rate results from Table XXII are likewise found in Table XXVII.

No significant difference was found on post test adjusted group means.

TABLE XXIV

TESTS ON DIFFERENCES BETWEEN PAIRS OF MEANS
FOR MAXIMAL ECCENTRIC BACK-LIFT STRENGTH

Groups		IV	I	II	III
	Means	335.015	355.120	382.467	417.398
IV	335.015	--	20.105	47.452	82.383
I	355.120		--	27.347	62.278
II	382.467			--	34.931
III	417.398				--

Truncated Range r	2	3	4
q.99 (r,35)	3.855	4.41	4.75
$\sqrt{MS'\ error\ (effective)/n}$ q.99 (r,35)	57.228	65.467	70.514
q.95 (r,35)	2.875	3.465	3.815
$\sqrt{MS'\ error\ (effective/n}$ q.95 (r,35)	42.680	51.438	56.634

	IV	I	II	III
IV		-	-	**
I			-	*
II				-
III				

** = .01 level of significance.

* = .05 level of significance.

TABLE XXV

ANALYSIS OF COVARIANCE - SUMMARY
EMG MEAN PEAK VOLTAGE

Source	df	Mean Squares	Adjusted F	p
Groups	3	81163.813	4.187	0.01
Within	35	19385.121		
RSQ = 0.494				

To evaluate training effects, t-tests for correlated samples were carried out on each group for maximal eccentric strength, EMG mean peak voltage, and heart rate. Table XXVIII demonstrates the t-test values for means as well as the probabilities of t's for differences between pre and post test means of Table XXII.

According to Table XXVIII all four groups increased in maximal eccentric back-lift strength - groups II and III beyond the .01 level and group I and IV not significantly. Group III increased on mean peak voltage from erectores spinae EMG's also at the .01 level. The other two training groups increased but not significantly. There were no significant decreases in heart rate, and it even increased slightly for group II.

The correlation matrix between pairs of variables computed at pretest, along with corresponding probabilities of t-values associated with correlation coefficients, is given

TABLE XXVI

TESTS ON DIFFERENCES BETWEEN PAIRS OF MEANS
FOR EMG MEAN PEAK VOLTAGE

Groups		IV	I	II	III
	Means	355.795	416.377	450.468	585.231
IV	355.795	--	60.582	94.673	229.436
I	416.377		--	34.091	168.854
II	450.468			--	134.763
III	585.231				--
Truncated Range r			2	3	4
q.99 (r,35)			3.855	4.41	4.75
$\sqrt{MS'\ error\ (effective)/n}$ q.99 (r,35)			175.472	200.734	216.210
q.95 (r,35)			2.875	3.465	3.815
$\sqrt{MS'\ error\ (effective)/n}$ q.95 (r,35)			130.864	157.720	173.651

	IV	I	II	III
IV		-	-	**
I			-	*
II				*
III				

** = .01 level of significance.

* = .05 level of significance.

TABLE XXVII

ANALYSIS OF COVARIANCE - SUMMARY
HEART RATE

Source	df	Mean Squares	Adjusted F	p
Groups	3	140.672	.807	0.50
Within	35	174.384		
RSQ = 0.275				

TABLE XXVIII

t-TESTS AND PROBABILITIES - ECCENTRIC TEST
SET BETWEEN PRE AND POST TEST

Variables	Groups (N=10)	t-Test Values for Means	Probabilities
Eccentric Back-Lift	I	-2.038*	0.07
Strength (Tbs.)	II	-3.988	0.003
	III	-4.066	0.003
	IV	-1.290	0.23
EMG Mean Peak	I	-1.061	0.32
Voltage (uV)	II	-1.550	0.16
	III	-4.065	0.003
	IV	1.063	0.32
Heart Rate (bpm)	I	0.711	0.50
	II	-0.422	0.68
	III	0.582	0.58
	IV	1.103	0.30

* Negative sign used when pretest mean minus post test mean is negative.

in Table XXIX.

TABLE XXIX

CORRELATION MATRIX AND PROBABILITIES - ECCENTRIC TEST SET

Variables	Eccentric Back-Lift Strength	EMG Mean Peak Voltage	Heart Rate
Eccentric Back-Lift Strength	1.00	.12 (p=.48)	.34 (p=.03)
EMG Mean Peak Voltage		1.00	.02 (p=.89)
Heart Rate			1.00

The only significant relationship found in Table XXIX was between maximal eccentric back-lift strength and heart rate (p=0.03).

Isometric Test Set for Efficiency. In order to test for changes in efficiency with regard to lumbar curvature, EMG mean peak voltage, and heart rate, all subjects repeated their isometric back-lift pretest maximum after training. The pretest means and means when pretest isometric back-lift strength was repeated are found in Table XXX.

The significance of observed differences on lumbar spinal curvature among means when the maximal pretest isometric back-lift scores were repeated after training (from Table XXX) was tested by analysis of covariance. Pretest scores were used as the covariate. Results are found in

TABLE XXX

MEANS OF VARIABLES AT PRETEST AND WHEN PRETEST ISOMETRIC BACK-LIFT STRENGTH REPEATED AFTER TRAINING - ISOMETRIC TEST SET FOR EFFICIENCY

Variables	Groups (N=10)	Pretest	Repeat Pretest Isometric Strength After Training
Lumbar Curvature (degrees)	I	14.55	10.80
	II	12.75	10.25
	III	14.10	10.35
	IV	12.00	11.90
EMG Mean Peak Voltage (uV)	I	353.78	296.34
	II	328.69	232.89
	III	292.13	274.35
	IV	434.24	399.32
Heart Rate (bpm)	I	102.90	99.00
	II	102.00	97.20
	III	108.00	102.60
	IV	96.00	91.80

Table XXXI.

The adjusted F value for groups was not quite significant at the .05 level.

Analysis of covariance was repeated on groups for EMG mean peak voltage. However, the adjusted F value for groups was not significant.

Lastly, a similar test was carried out on groups for heart rate post test means of Table XXX. Results are dis-

TABLE XXXI

ANALYSIS OF COVARIANCE - SUMMARY
CURVATURE

Source	df	Mean Squares	Adjusted F	p
Groups	3	19.806	2.738	0.058
Within	35	7.234		
RSQ = 0.765				

TABLE XXXII

ANALYSIS OF COVARIANCE - SUMMARY
EMG MEAN PEAK VOLTAGE

Source	df	Mean Squares	Adjusted F	p
Groups	3	17692.957	1.716	0.18
Within	35	10311.000		
RSQ = 0.494				

played in Table XXXIII. Once again, the adjusted F value for groups was not significant.

In order to look at any efficiency changes due to training, t-tests for correlated samples were calculated for each group on each of the three variables. These t-values for means and probabilities of t's for any differences between pretest means and when pretest isometric back-lift strength

TABLE XXXIII

ANALYSIS OF COVARIANCE - SUMMARY
HEART RATE

Source	df	Mean Squares	Adjusted F	p
Groups	3	25.554	0.286	0.84
Within	35	89.322		
RSQ = 0.418				

was repeated after training (see Table XXX) are outlined in Table XXXIV.

As can be seen from Table XXXIV, lumbar spinal curvature was reduced after training for all groups. This reduction was significant for groups I, II, and III at the .05 level of significance for groups I and II and the .01 level for group III. EMG mean voltages from erectores spinae also decreased for each group but this reduction was only significant for the control group where the two sets of scores were most correlated with one another. Heart rate was also lower for all groups but none of these differences was significant.

Discussion

Reliabilities. The reliability coefficients for strength, electromyographical, and heart rate measures over the three test sets were 0.83, 0.92, and 0.92 respectively. A value of 0.95

TABLE XXXIV

t-TESTS AND PROBABILITIES - ISOMETRIC TEST SET FOR EFFICIENCY BETWEEN PRE AND REPEATED PRETEST ISOMETRIC BACK-LIFT STRENGTH AFTER TRAINING

Variables	Groups (N=10)	t-Test Values for Means	Probabilities
Lumbar Curvature (degrees)	I	2.700	0.02
	II	2.246	0.05
	III	3.833	0.004
	IV	0.802	0.44
EMG Mean Peak Voltage (uV)	I	1.463	0.18
	II	1.837	0.10
	III	0.461	0.66
	IV	3.308	0.009
Heart Rate (bpm)	I	1.778	0.11
	II	0.937	0.37
	III	2.077	0.07
	IV	1.353	0.21

was recorded by the author for maximal isometric back-lift strength in a previous study (25). Corresponding estimates for lumbar curvature and trunk flexion strength were 0.92 and 0.91 with the confounding of treatment effects included. These values are supported by previous research findings (6,8,21).

Strength. The mean pretest strength scores for all forty subjects (average age = 23 years) were 315.31 pounds for eccentric back-lift strength, 304.69 pounds for isometric

back-lift strength, and 222.94 pounds for concentric back-lift strength. The eccentric and isometric means were significantly higher than the concentric mean ($p < .01$). This same order from high to low was also found by Olson et al (23) involving hip abductor muscles, with the eccentric contraction developing the greatest tension. Asmussen (1) explains this by stating that 'a fibre lengthening in eccentric work necessarily produces more force than when it is shortening because of the relatively fewer number of fibres needed to hold the load.' Expressed as percentages, the mean pretest eccentric force of back extensors in this study was 41.43 percent greater than concentric and 3.48 percent greater than the isometric force. Doss et al (13) found corresponding percentages of 45.6 and 13.5 for elbow flexors; while Singh and Karpovich (27) found the eccentric force of elbow extensors 14.22 percent greater than the concentric force.

The isometric pretest mean of 304.69 pounds was slightly higher than values of 215.6, 212.3, 234.66 and 164.75 pounds found by Troup and Chapman (30), Chapman and Troup (7), Clarke (9), and Morris et al (22) respectively on college males. However a mean of 362.29 pounds was reported on college males (average age = 24 years) by Singh and Ashton (25) in a previous study. Falls (16) reports mean trunk extension strength scores of 179.52 and 192.28 pounds for subjects with average age of 20 and 25 years respectively. Davis (11) calculated the theoretical maximal isometric back-lift at 30 degrees from vertical to be approximately 500 pounds. The

maximum score in this study was 550 pounds at 20 degrees from vertical. The pretest mean antagonist or isometric trunk flexion score of 91.91 pounds was much less than the mean of 165 pounds reported by Troup and Chapman (30).

The concentric and eccentric pretest means of 222.94 and 315.31 pounds were also much higher than the mean maximal back hyperextension value of 75.62 pounds reported by Berger (4).

Clarke (10) had reported correlations of 0.58 and 0.51 between maximal isometric back-lift strength and body weight and maximal isometric back-lift strength and maximal trunk flexion strength. These relationships were not found to be so close with values of 0.17 and 0.35 in this study. The correlation between maximal isometric back-lift strength and height was even lower ($r = 0.10$).

On maximal isometric back-lift strength, and maximal concentric back-lift strength, each training group did significantly better at post test than the control group. For maximal eccentric back-lift strength, the eccentric group did significantly better after training than the control group and isometric group.

In the isometric test set, the eccentric and isometric groups made the most significant mean strength gains (87.25 and 84 pounds respectively). The concentric group also increased significantly by 55.95 pounds. This would suggest that static strength of back muscles can be improved significantly both by static and dynamic training. Berger (4) had

found that static strength was improved more by training statically than dynamically; however, the gains of 11.13 and 7.3 pounds respectively were both significant. The isometric group in this study was the only group to make a significant gain in maximal isometric trunk-flexion strength (18.30 pounds). Thus static training of the agonists was reflected in a significant gain in static strength by the antagonists.

In the concentric test set, the concentric group made the greatest mean strength gain. This mean gain was 108.5 pounds as compared to significant gains of 103.25 and 86.75 pounds for the eccentric and isometric groups respectively.

For the eccentric test set, the eccentric group made the greatest mean strength gain. This gain was 97.5 pounds and was significant; whereas gains for the concentric and isometric groups were 70.75 (significant) and 40.5 (non-significant) pounds respectively. This is in agreement with Berger's (4) work where dynamic back strength was improved more by training dynamically than statically (21.15 pound gain vs. 9.43 pound gain).

The fact that eccentric strength training is a significant stimulus for improving concentric strength (actual weight-lifting), has been substantiated by this study. The eccentric training group improved their maximal concentric back-lift strength by 46.3 percent, their maximal eccentric back-lift strength by 30.1 percent, and maximal isometric back-lift strength by 29.8 percent. With training forearm

extensors eccentrically for eight weeks, Singh and Karpovich (26) found corresponding values of 42.8 percent for concentric strength, 22.9 percent for eccentric strength, and 40.3 percent for isometric strength. However, in this study, the concentric group made a slightly better increase than the eccentric group on maximal concentric back-lifting (108.5 pounds vs. 103.25 pounds).

The mean gain of all subjects in this study taken together on maximal isometric back strength was 64.4 pounds as compared to a mean gain of 57 pounds after four weeks of isometric exercises in a study done by Baley (3).

Research done by Berger (4) and Rasch and Morehouse (24) supports the idea that static strength is improved more by training statically; and dynamic strength is improved more by training dynamically. Asmussen (2) suggests that each type of training produces the same degree of improvement.

This study would have to be more in agreement with Falls (16:36) who states that

> 'Dynamic muscle training will increase the isometric strength of the muscles undergoing training in proportion to the loads they have been opposing, and at the same time it will increase the capacity for performing the training exercises and the endurance in performing them.'

In this case dynamic training, namely eccentric, was as successful in eliciting isometric strength gains as static training; whereas dynamic training was better for dynamic strength gains (i.e., concentric for concentric, and eccentric for eccentric).

Lifting Stress and Lumbar Curvature. Lumbar curvature measurements of the total displacement in degrees from L1 to L5 was restricted to the isometric test set and the isometric test set for efficiency.

In the pretest, and considering all subjects, the probability of the correlation between maximal isometric back-lift strength and lumbar curvature was not significant ($p=0.29$). Flint and Diell (18) had earlier found a significant relationship between back strength and antero-posterior alignment in females ($p=0.05$). However it was found in this study that increases in maximal isometric back-lift strength after training occurred with slightly flatter, lumbar spines. This is in agreement with the Harvard University's A rating (strongest back) as being associated with flat backs (31).

In the isometric test set, the increases in maximal isometric back-lift strength by the three training groups were accompanied by slight but not statistically significant reductions in lumbar spinal curvature (highest reduction being two degrees for the isometric group). The fact that isometric, concentric, and eccentric groups made gains of 84.0, 55.95, and 87.25 pounds respectively on maximal isometric back-lift strength with slightly reduced lumbar spinal curvature may suggest something in the way of efficiency alterations with training.

In the isometric test set for efficiency the probability of a difference among the groups after training was 0.058 when they repeated their pretest maximal isometric back-lift

strength scores. However the isometric, concentric, and eccentric group means for lumbar curvature had been reduced by 3.75, 2.50 and 3.75 degrees respectively. This drop was significant at the .05 level for the isometric and concentric group; and at the .01 level for the eccentric group.

Using the average maximal isometric back-lift strength for the forty subjects of 304.69 pounds, with the back 20 degrees from the vertical, and the average weight of the subjects of 166.95 pounds; the model of Morris et al (22) was used to calculate the approximate compressive force perpendicular to the disc between L_5 - S_1 and T_{10} - T_{11}. With the effect of body cavity pressures included, these resultant compressive forces were approximately 2318.91 and 1559.12 pounds respectively. The corresponding tensions in the erectores spinae according to the model were 2164.60 and 1337.83 pounds respectively. Morris et al (22) found a compressive force between L_5 - S_1 of 1483 pounds when lifting 200 pounds with the back 40 degrees from the vertical, with a corresponding tension of 1439 pounds in the erectores spinae muscle. When 440 pounds were held in the stooped position, Groh et al (19) calculated extensor forces in the back muscles as high as 3498 pounds. Strait et al (28) reported tension in the erectores spinae of 850 pounds just when 50 pounds was lifted at 60 degrees from the vertical. Other compression force values reported were 323.5 kilograms perpendicular to L_5 while lifting 130 kilograms at 60 degrees from vertical by Eie and Wehn (15); 427 kilograms at the

lumbosacral level while lifting 50 pounds with knees extended by Fisher (17); and 527 kilograms on the L_4 - L_5 disc when standing in support of 98 kilograms by Troup and Chapman (30). From these values one can see that the approximate compressive forces derived in this study are quite high.

Assuming from the above that the compressive forces are approximately 2318.91 pounds between L_5 and S_1 and 1559.12 pounds between T_{10} and T_{11}; it might then be assumed that the compressive force (F) at the level of L1 is somewhere between these two values (e.g., 1600, 1800, 2000 or 2200 pounds). Since the average change in curvature (i.e., the angle subtended by the lines perpendicular to the L1 and L5 points on the curve) was 13.35 degrees (θ) for the forty subjects; it is possible to calculate the approximate shear force through the lumbar region by multiplying the compressive force (F) by the sine of the angle of displacement (θ) through the lumbar segment. For a curvature of 13.35 degrees, these shear values would be 368, 414, 460, and 506 pounds respectively for the above compressive forces at L1 of 1600, 1800 2000 and 2200 pounds. If the lower back becomes one, two, three, or four degrees straighter than 13.35 degrees (as was the case after training); the shear force is found to be reduced by 8.7, 14.7, 22.3, and 30.4 percent respectively with a proportionate rise in compression. In this study then, the shear force would have been reduced by as much as 30 percent for the isometric and eccentric group; and approximately 20 percent for the concentric group when they repeated their

pretest isometric back-lift strength score after training. Considering that the resistance of the lumbar spine to shear force is low, as compared to the resistance to compression (14); this has to be a very important conclusion.

As an explanation of why the lumbar spine had become straighter, Klausen (21) suggests that an increased pull of gravity gives rise to a flattening of the lumbar lordosis probably due to a deformation of the discs. This, along with increased electrical activity of the lower back muscles and possible increased body cavity pressures, may apply to the isometric test set where subjects lifted more with slightly less lumbar curvature. However, in the isometric test set for efficiency where subjects repeated their original pretest maximum after training, this reasoning would not explain the more pronounced decreases in lumbar curvature since the weight lifted was the same in both cases. The straigthening that did occur in this test set might be explained by efficiency changes in the back musculature (assuming the hips and shoulders are relatively fixed) as evidenced by a slight drop in electrical activity after training (see Table XXX). This possibility of each fibre doing more work, along with body cavity pressure changes and possible alterations in spinal and pelvic mechanics due to training might provide some insight to the explanation.

EMG's. The mean peak voltages from the lumbar erectores spinae using surface electrodes in the isometric test set at pretest ranged from 113.12 to 866.08 microvolts with the mean

maximal isometric back-lift strength being 304.69 pounds. Falls (16) had found mean voltages as high as 180 microvolts with isometric back pulls up to 154 pounds, and Morris et al (22) obtained peak values as high as 8000 microvolts for 200 pound static pulls at 30 degrees from vertical using needle electrodes.

Using pretest scores for all subjects, correlation coefficients between strength and mean electrical activity of lumbar erectores spinae for the isometric, concentric, and eccentric test sets were 0.24, 0.28, and 0.12 respectively. This supports the work of Bigland and Lippold (5) who found that the linear relationship between tension and voltage for submaximal isometric contractions did not hold true for maximal ones. Zuniga et al (33) also found a non-linear relationship. Grossman (20) supports linearity over certain ranges, and his finding that the slopes are different for isometric versus isotonic contractions has been substantiated in this study. The slopes for the voltage/force for pretest maximal isometric, concentric, and eccentric back-lift strength in this study were 1.18, 1.85, and 1.29 respectively considering all subjects.

In the isometric test set significant gains in maximal isometric back-lift strength by the three training groups were paralleled by significant increases in erectores spinae electrical activity by the isometric and concentric groups. The probability for the increase of the eccentric group being significant was 0.14. For the most part, this would suggest

that the strength increases were due mainly to an increase in motor unit activity as found by Chapman and Troup (7).

In the concentric test set significant gains in maximal concentric back-lift strength made by the three training groups (the concentric group making the greatest gain) were paralleled by significant increases in electrical activity by the three training groups (the eccentric group making the greatest gain). This also supports the idea that strength increases were generally due to increased motor unit activity.

In the eccentric test set significant gains in maximal eccentric back-lift strength made by the eccentric and concentric groups were paralleled by significant increases in electrical activity by the eccentric group. The probability for the increase of the concentric group being significant was 0.16. In fact, the eccentric group had mean voltage values significantly higher than the other three groups whereas this same group had eccentric strength values significantly higher than the control and isometric groups. Considering, however, that all training groups had increased their electrical activity while increasing their strength, again supports the idea that eccentric strength gains were due to increased motor unit activity, especially in the case of the eccentric training group. The isometric and concentric groups made eccentric strength gains of 40.5 pounds and 70.75 pounds with increased electrical activity probabilities of 0.32 and 0.16 respectively.

In the isometric test set for efficiency specifically,

where subjects repeated their original pretest maximum isometric back-lift strength, none of the three training groups had significantly lower values for lumbar erectores spinae mean electrical activity. However the values for the three training groups were slightly lower. DeVries (12) has stated that in exercises involving hypertrophy, strength increases led to a reduction in electrical activity for a given external force since the capacity of the fibres to develop tension can increase. In this study however, no significant reduction occurred.

Heart Rate. For the isometric, concentric, and eccentric test sets, there were no significant differences between the groups on heart rate as a result of training. For each group in each test set, heart rate values were lower after training but not significantly lower except for the control group in the concentric test set; and the heart rate had risen but not significantly for the concentric group in the eccentric test set. The fact that the heart rate did not rise as the strength did, may suggest a possible improvement in efficiency.

In the isometric test set for efficiency heart rate values were slightly but not significantly lower for all groups. The probability for a significant drop for eccentric group was .068.

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CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to determine the effects of maximal isometric, concentric, and eccentric back-lift strength training on maximal isometric, concentric and eccentric back-lift strength; lumbar spinal curvature during maximal isometric back-lifting, and erectores spinae electromyograms during maximal isometric, concentric, and eccentric back-lift contractions with the back 20 degrees from the vertical. Heart rate was recorded during and immediately following the lifting contractions. A sub-problem was to measure the maximal isometric hip-flexion strength at the 160 degree hip angle before and after training. An electrogoniometer was used to measure hip angle throughout the tests. Three different training groups and a control were compared.

Forty male students (average age = 23.4 years) in attendance at the University of Alberta served as subjects. Each subject was ranked at pretest according to total strength score (isometric + concentric + eccentric) and randomly blocked into one of three training groups or control group (N = 10 per group). Each subject in each training group performed three maximal three-second trials three days per week

(MWF) for five weeks.

The isometric test set consisted of one maximal isometric back-lift at a hip angle of 160 degrees; and one maximal isometric hip-flexion strength test at the same angle. The concentric test set involved one maximal concentric back-lift through a hip angle range of 150 to 170 degrees; while the eccentric test set consisted of one maximal eccentric back-lift through a hip angle range of 170 to 150 degrees. The isometric test set for efficiency was carried out only at post test where each subject performed one isometric back-lift equal in magnitude to his original pretest maximum. All measurements were taken with the back 20 degrees from the vertical (i.e., 160 degree hip angle).

Analysis of covariance on post test strength scores yielded significant differences between each training group as compared to the control group for both the isometric and concentric test sets at the .05 level. Each training group increased significantly on back-lift strength in these two test sets ($p < .01$). In the eccentric test set, the eccentric group did significantly better after training than the control group ($p = .01$) and the isometric group ($p = .05$).

In the isometric test set, the isometric and eccentric groups made the most significant mean strength gains. t-test probabilities for these two groups were .002 and .003 respectively. The isometric group also made a significant gain on maximal isometric trunk-flexion strength ($p = .002$). In the concentric test set, the concentric group made the

most significant mean strength gain ($p = .000$); and the eccentric and concentric group made similar mean strength gains in the eccentric test set ($p = .003$).

In the isometric test set, analysis of covariance produced no significant differences between post test group means on lumbar spinal curvature, although this curvature was reduced slightly for each group after training. Analysis of covariance, in the isometric test set for efficiency, yielded a probability of .058 for any difference between groups on lumbar spinal curvature. t-tests, however, showed a significant reduction at the .05 level for the isometric and concentric groups; and at the .01 level for the eccentric group.

In the isometric test set, analysis of covariance did not yield any significant difference between groups on post test erectores spinae electrical activity. However, t-tests showed that the isometric and concentric groups had made significant gains at the .05 and .01 level respectively. For the concentric test set, the eccentric and concentric groups had significantly higher post test mean voltage values than the control group ($p = .05$). t-tests showed significant gains for the isometric and concentric groups at the .05 level and the eccentric group beyond the .01 level. In the eccentric test set, the eccentric group had a post test mean voltage value significantly higher than the other three groups ($p = .01$), and had made the only significant increase ($p = .003$). In the isometric test set for efficiency, there was no significant difference between the groups on mean peak

voltage when repeating their original pretest isometric back-lift strength score. Also t-tests showed that none of the training groups had significantly lower values for lumbar erectores spinae electrical activity.

For the isometric, concentric, and eccentric test sets, analysis of covariance yielded no significant differences between the groups on heart rate. Although training seemed to lower the heart rate, these differences were not significant. In the isometric test set for efficiency, no significant differences on heart rate were observed. Again, heart rate values were slightly but not significantly lower for all groups.

Conclusions

On the basis of the statistical analysis, the following conclusions are justifiable:

(1) Maximal isometric back-lift strength was significantly increased by means of isometric, concentric, and eccentric maximal back-lift strength training.

(2) Maximal isometric trunk-flexion strength was significantly increased by means of maximal isometric back-lift strength training only.

(3) Maximal concentric back-lift strength was significantly increased by means of isometric, concentric, and eccentric maximal back-lift strength training.

(4) Maximal eccentric back-lift strength was significantly increased by means of concentric and eccentric maximal

back-lift strength training.

(5) Lumbar spinal curvature during maximal isometric back-lifting was not significantly reduced by means of isometric, concentric, and eccentric maximal back-lift strength training.

(6) Lumbar spinal curvature during isometric back-lifting was significantly reduced by means of isometric, concentric, and eccentric maximal back-lift strength training when pretest isometric back-lift strength values were repeated after training.

(7) Electrical activity of the lumbar erectores spinae during maximal isometric back-lifting was significantly increased by means of isometric and concentric maximal back-lift strength training.

(8) Electrical activity of the lumbar erectores spinae during maximal concentric back-lifting was significantly increased by means of isometric, concentric, and eccentric maximal back-lift strength training.

(9) Electrical activity of the lumbar erectores spinae during maximal eccentric back-lifting was significantly increased by means of maximal eccentric back-lift strength training.

(10) Electrical activity of the lumbar erectores spinae during isometric back-lifting was not significantly reduced by means of isometric, concentric, or eccentric maximal back-lift strength training when pretest isometric back-lift strength values were repeated after training.

(11) Heart rate values immediately following isometric, concentric, or eccentric maximal back-lift strength contractions were not significantly lowered by means of isometric, concentric, or eccentric maximal back-lift strength training.

(12) Heart rate values immediately following isometric back-lifting were not significantly lowered by means of isometric, concentric, or eccentric maximal back-lift strength training when pretest isometric back-lift strength values were repeated after training.

Thus, the study showed that the lumbar spine was trained, and more importantly its curvature reduced resulting in significant reduction of shear stress. This would therefore suggest that the training programs used in this study enabled the subjects to become less prone to risk of injury when lifting with the back 20 degrees from vertical.

Recommendations

It is recommended that spinal curvature changes due to training be further studied by radiological and other techniques, and that training effects on intra-abdominal pressure during lifting be assessed.

This, along with co-ordinated efforts by the physical education and medical professions, will lead to better understanding of the spine's response to training throughout its normal range of movement.

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APPENDIX A

RAW DATA

ISOMETRIC TEST SET - ISOMETRIC STRENGTH (POUNDS)

Group	Subject	Pre	Post
	1	315	350
	2	275	352.5
	3	252.5	297.5
	4	362.5	405
Isometric	5	260	402.5
	6	420	495
	7	150	342.5
	8	325	375
	9	380	390
	10	380	550
	11	330	335
	12	400	452.5
	13	287.5	417
	14	310	397.5
Concentric	15	205	307.5
	16	265	380
	17	330	357.5
	18	385	387.5
	19	352.5	375
	20	345	360
	21	295	380
	22	230	365
	23	225	397.5
	24	257.5	320
Eccentric	25	240	330
	26	320	410
	27	405	400
	28	270	357.5
	29	415	380
	30	270	460
	31	240	350
	32	355	360
	33	320	350
	34	275	250
Control	35	270	332.5
	36	245	290
	37	300	327.5
	38	230	300
	39	400	395
	40	295	280

ISOMETRIC TEST SET - CURVATURE (DEGREES)

Group	Subject	Pre	Post
	1	13.5	7
	2	8.5	4.5
	3	32	20
	4	4.5	4.5
Isometric	5	12	12
	6	17.5	15
	7	10	8
	8	18.5	18
	9	25	26.5
	10	4	10
	11	13.5	15
	12	7	6
	13	8.5	6.5
	14	9	8.5
Concentric	15	12	16
	16	10	10
	17	15.5	15
	18	15	16.5
	19	17.5	13.5
	20	19.5	12.5
	21	8	4
	22	8	6
	23	12.5	11.5
	24	14	15.5
Eccentric	25	17	21.5
	26	14	11
	27	18	21
	28	9.5	10
	29	14	12
	30	26	22.5
	31	10.5	10.5
	32	10	11
	33	5.5	6.5
	34	23	21
Control	35	11	12
	36	6.5	7
	37	11.5	10.5
	38	6	8
	39	26	23
	40	10	10.5

ISOMETRIC TEST SET - EMG MEAN PEAK VOLTAGE (MICROVOLTS)

Group	Subject	Pre	Post
	1	373.30	424.20
	2	176.75	185.59
	3	742.35	866.08
	4	233.31	593.88
Isometric	5	454.95	565.60
	6	459.55	459.55
	7	132.56	88.38
	8	240.38	304.01
	9	406.53	475.10
	10	318.15	381.78
	11	238.61	185.59
	12	866.08	795.38
	13	265.13	291.64
	14	441.88	600.95
Concentric	15	176.75	349.97
	16	254.52	424.20
	17	159.08	325.22
	18	388.85	466.62
	19	186.65	388.85
	20	309.31	424.20
	21	282.80	176.75
	22	287.75	353.50
	23	183.82	300.48
	24	388.85	972.13
Eccentric	25	113.12	353.50
	26	265.13	618.63
	27	233.31	441.88
	28	512.58	318.15
	29	388.85	427.74
	30	265.13	176.75
	31	470.16	494.90
	32	443.29	427.74
	33	311.08	282.80
	34	254.52	174.98
Control	35	583.28	604.49
	36	353.50	371.18
	37	282.80	254.52
	38	371.18	583.28
	39	530.25	353.50
	40	742.35	707.00

ISOMETRIC TEST SET - HEART RATE (BPM)

Group	Subject	Pre	Post
	1	108	108
	2	102	108
	3	114	102
	4	102	90
Isometric	5	96	90
	6	114	114
	7	84	66
	8	90	96
	9	114	102
	10	105	140
	11	96	78
	12	102	90
	13	96	102
	14	90	96
Concentric	15	96	96
	16	90	90
	17	120	120
	18	96	96
	19	96	114
	20	138	96
	21	120	102
	22	96	96
	23	96	90
	24	108	114
Eccentric	25	90	84
	26	102	96
	27	120	114
	28	114	114
	29	126	96
	30	108	114
	31	96	90
	32	96	84
	33	96	72
	34	96	96
Control	35	120	120
	36	84	90
	37	84	78
	38	84	78
	39	126	120
	40	78	84

ISOMETRIC TEST SET - TRUNK FLEXION STRENGTH (POUNDS)

Group	Subject	Pre	Post
	1	89	85.5
	2	70	85.5
	3	66	82.5
	4	127	133.5
Isometric	5	64	73.5
	6	106	127
	7	42.5	75.5
	8	78.5	101.5
	9	50.5	70
	10	223	265
	11	83	75.5
	12	101.5	79.5
	13	93	127
	14	72.5	148.5
Concentric	15	111	89.5
	16	66	85.5
	17	104	109
	18	83	101.5
	19	68.5	60.5
	20	146.5	140
	21	101.5	115
	22	83.5	86
	23	100	101.5
	24	104	113
Eccentric	25	89	85.5
	26	107.5	106
	27	101.5	75.5
	28	35.5	57.5
	29	139.5	108
	30	127.5	135.5
	31	91.5	98
	32	83	68.5
	33	70	69
	34	47	60
Control	35	115	108
	36	66	66
	37	54.5	54.5
	38	111	123
	39	102.5	102.5
	40	101	72

CONCENTRIC TEST SET - CONCENTRIC STRENGTH (POUNDS)

Group	Subject	Pre	Post
	1	155	222.5
	2	130	235
	3	225	277.5
	4	260	300
Isometric	5	167.5	330
	6	375	397.5
	7	145	295
	8	270	310
	9	295	305
	10	190	407.5
	11	215	262.5
	12	380	422.5
	13	135	330
	14	185	355
Concentric	15	110	225
	16	165	340
	17	185	317.5
	18	250	335
	19	320	355
	20	230	317.5
	21	325	382.5
	22	125	357.5
	23	212.5	352.5
	24	190	270
Eccentric	25	255	230
	26	150	310
	27	245	245
	28	135	267.5
	29	375	380
	30	215	465
	31	220	320
	32	317.5	282.5
	33	220	325
	34	115	110
Control	35	230	190
	36	185	240
	37	255	325
	38	295	215
	39	315	325
	40	150	227.5

CONCENTRIC TEST SET - EMG MEAN PEAK VOLTAGE (MICROVOLTS)

Group	Subject	Pre	Post
	1	233.31	318.15
	2	220.94	265.13
	3	1025.15	1141.81
	4	291.64	494.90
Isometric	5	408.29	494.90
	6	353.50	265.13
	7	220.94	176.75
	8	279.27	319.21
	9	335.83	509.04
	10	243.92	445.41
	11	318.15	265.13
	12	1237.25	890.82
	13	282.80	388.85
	14	618.63	777.70
Concentric	15	282.80	777.70
	16	445.41	593.88
	17	141.40	424.20
	18	311.08	583.28
	19	163.32	388.85
	20	309.31	707.00
	21	325.22	212.10
	22	209.27	441.88
	23	212.10	420.67
	24	388.85	680.49
Eccentric	25	176.75	441.88
	26	282.80	760.03
	27	222.71	530.25
	28	353.50	330.88
	29	353.50	680.49
	30	176.75	530.25
	31	470.16	480.76
	32	466.62	388.85
	33	311.08	229.78
	34	169.68	127.26
Control	35	820.12	565.60
	36	530.25	565.60
	37	565.60	579.74
	38	611.56	583.28
	39	441.88	441.88
	40	777.70	795.38

CONCENTRIC TEST SET - HEART RATE (BPM)

Group	Subject	Pre	Post
Isometric	1	108	102
	2	108	108
	3	132	102
	4	102	96
	5	114	90
	6	114	102
	7	90	90
	8	90	102
	9	114	108
	10	84	126
Concentric	11	96	90
	12	114	108
	13	96	108
	14	90	90
	15	114	108
	16	96	96
	17	108	126
	18	105	114
	19	96	120
	20	150	96
Eccentric	21	138	114
	22	96	102
	23	108	108
	24	108	114
	25	108	84
	26	102	96
	27	120	114
	28	126	108
	29	144	102
	30	114	114
Control	31	102	102
	32	102	96
	33	96	84
	34	96	96
	35	126	102
	36	84	90
	37	96	90
	38	90	72
	39	132	126
	40	96	84

ECCENTRIC TEST SET - ECCENTRIC STRENGTH (POUNDS)

Group	Subject	Pre	Post
	1	320	320
	2	230	270
	3	302.5	302.5
	4	395	397.5
Isometric	5	280	372.5
	6	417.5	397.5
	7	240	352.5
	8	280	360
	9	355	310
	10	320	462.5
	11	255	340
	12	405	450
	13	230	400
	14	275	390
Concentric	15	225	317.5
	16	280	387.5
	17	377.5	360
	18	402.5	400
	19	340	407.5
	20	295	340
	21	357.5	485
	22	385	472.5
	23	270	430
	24	200	352.5
Eccentric	25	402.5	410
	26	375	425
	27	405	410
	28	140	375
	29	390	415
	30	315	440
	31	267.5	362.5
	32	400	382.5
	33	400	435
	34	190	275
Control	35	310	312.5
	36	325	340
	37	380	350
	38	290	350
	39	405	415
	40	180	125

ECCENTRIC TEST SET - EMG MEAN PEAK VOLTAGE (MICROVOLTS)

Group	Subject	Pre	Post
Isometric	1	303.30	275.73
	2	176.75	212.10
	3	883.75	919.10
	4	291.64	494.90
	5	514.70	565.60
	6	353.50	247.45
	7	132.56	141.40
	8	212.10	319.21
	9	459.55	339.36
	10	318.15	483.59
Concentric	11	190.89	176.75
	12	866.08	692.86
	13	247.45	291.64
	14	530.25	636.30
	15	335.83	661.05
	16	360.57	542.98
	17	190.89	282.80
	18	466.62	489.95
	19	233.31	353.50
	20	397.69	353.50
Eccentric	21	282.80	265.13
	22	261.59	486.06
	23	353.50	396.63
	24	427.74	777.70
	25	141.40	441.88
	26	406.53	848.40
	27	371.18	707.00
	28	265.13	381.78
	29	194.43	563.83
	30	265.13	265.13
Control	31	537.32	565.60
	32	513.28	466.62
	33	388.85	311.08
	34	395.92	353.50
	35	629.94	671.65
	36	353.50	424.20
	37	707.00	424.20
	38	494.90	629.94
	39	441.88	441.88
	40	494.90	176.75

ECCENTRIC TEST SET - HEART RATE (BPM)

Group	Subject	Pre	Post
	1	90	84
	2	84	102
	3	108	96
	4	96	96
Isometric	5	102	84
	6	120	108
	7	84	66
	8	90	96
	9	114	108
	10	126	144
	11	72	84
	12	102	102
	13	78	90
	14	78	96
Concentric	15	96	90
	16	90	90
	17	108	120
	18	96	102
	19	84	114
	20	144	90
	21	126	108
	22	90	96
	23	108	96
	24	90	114
Eccentric	25	102	84
	26	102	90
	27	108	108
	28	96	120
	29	120	102
	30	114	108
	31	90	84
	32	96	90
	33	84	72
	34	96	96
Control	35	114	114
	36	72	84
	37	72	78
	38	72	72
	39	132	114
	40	78	72

ISOMETRIC TEST SET FOR EFFICIENCY -
CURVATURE (DEGREES)

Groups	Subject	Pre	Repeat Pre (Isom.)
	1	13.5	8.5
	2	8.5	4
	3	32	17.5
	4	4.5	4.5
Isometric	5	12	10.5
	6	17.5	12.5
	7	10	10
	8	18.5	13
	9	25	24
	10	4	3.5
	11	13.5	13
	12	7	4
	13	8.5	7.5
	14	9	6
Concentric	15	12	13
	16	10	9.5
	17	15.5	14
	18	15	15
	19	17.5	12
	20	19.5	8.5
	21	8	4.5
	22	8	5.5
	23	12.5	10.5
	24	14	8.5
Eccentric	25	17	17
	26	14	9.5
	27	18	13.5
	28	9.5	9
	29	14	10.5
	30	26	15
	31	10.5	10
	32	10	10
	33	5.5	5
	34	23	23.5
Control	35	11	11
	36	6.5	6.5
	37	11.5	11
	38	6	6
	39	26	25.5
	40	10	10.5

ISOMETRIC TEST SET FOR EFFICIENCY -
EMG MEAN PEAK VOLTAGE (MICROVOLTS)

Groups	Subject	Pre	Post
	1	373.30	353.50
	2	176.75	203.26
	3	742.35	721.14
	4	233.31	176.75
Isometric	5	454.95	176.75
	6	459.55	176.75
	7	132.56	070.70
	8	240.38	304.01
	9	406.53	424.20
	10	318.15	356.33
	11	238.61	176.75
	12	866.08	353.50
	13	265.13	194.43
	14	441.88	247.45
Concentric	15	176.75	155.54
	16	254.52	271.49
	17	159.08	212.10
	18	388.85	424.20
	19	186.65	116.66
	20	309.31	176.75
	21	282.80	212.10
	22	287.75	220.94
	23	183.82	180.29
	24	388.85	406.53
Eccentric	25	113.12	176.75
	26	265.13	371.18
	27	233.31	353.50
	28	512.58	267.25
	29	388.85	466.62
	30	265.13	088.38
	31	470.16	424.20
	32	443.29	427.74
	33	311.08	243.92
	34	254.52	176.75
Control	35	583.28	540.86
	36	353.50	335.83
	37	282.80	282.80
	38	371.18	373.30
	39	530.25	530.25
	40	742.35	657.51

ISOMETRIC TEST SET FOR EFFICIENCY -
HEART RATE (BPM)

Groups	Subject	Pre	Repeat Pre (Isom.)
	1	108	108
	2	102	114
	3	114	102
	4	102	96
Isometric	5	96	90
	6	114	102
	7	84	78
	8	90	90
	9	114	108
	10	105	102
	11	96	96
	12	102	102
	13	96	90
	14	90	90
Concentric	15	96	96
	16	90	84
	17	120	114
	18	96	102
	19	96	108
	20	138	90
	21	120	108
	22	96	90
	23	96	96
	24	108	108
Eccentric	25	90	84
	26	102	96
	27	120	126
	28	114	114
	29	126	102
	30	108	102
	31	96	84
	32	96	96
	33	96	84
	34	96	102
Control	35	120	108
	36	84	96
	37	84	78
	38	84	66
	39	126	120
	40	78	84

APPENDIX B

FORMULAE

A. Standard Error of Measurement Formula

$$S_m = S_t\sqrt{1-r}$$

Where S_m = Standard Error of Measurement

S_t = Standard Deviation of Scores

r = Reliability Coefficient.

APPENDIX C

DATA COLLECTION SHEET

DATA SHEET

NAME _____ FACULTY _____ AGE _____ (Yrs. & Months)

HEIGHT _____ (Inches) WEIGHT _____ (Pounds)

TRAINING GROUP (Blank) _____

PRETEST

Variables	#1 Isom. B-L	#2 Conc. B-L	#3 Ecc. B-L	#4 Flex. Test
Dyn. Position Dial (Inches)	___	___ to ___	___ to ___	
1. Strength (lbs.)				___
2. Curvature at max. (160°)		___	___	Tensi lbs.
3. EMG (MV)				___
4. HR (bpm) Immed. After				___

TRAINING PERIODS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

DATA SHEET

NAME _____ FACULTY _____ AGE _____ (Yrs. & Months)

HEIGHT _____ (Inches) WEIGHT _____ (Pounds)

TRAINING GROUP (Blank) _____

POST TEST

Variables →	#1 Isom. B-L	#2 Conc. B-L	#3 Ecc. B-L	#4 Flex. Test	#5 Isom.-Orig. Max. (Pre #1)
Dyn. Position Dial (Inches)	same	to same	to same		same
1. Strength (lbs.)				—	
2. Curvature at max. (160°)		—	—	Tensi lbs.	
3. EMG (MV)				—	
4. HR (bpm) Immed. After				—	

TRAINING PERIODS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

APPENDIX D

ANTHROPOMETRICAL DATA

ANTHROPOMETRICAL DATA

Group	Subject	Age (Months)	Height (Inches)	Weight (Pounds)
	1	269	69	145
	2	256	71	150
	3	260	71	155
	4	260	72	190
Isometric	5	276	66	150
	6	275	70	195
	7	275	70	180
	8	269	72	150
	9	283	69	150
	10	311	74	200
	11	268	67	150
	12	262	76	200
	13	257	72	160
	14	269	71	176
Concentric	15	264	70	140
	16	254	68.5	165
	17	354	68	158
	18	286	68	145
	19	285	75	195
	20	260	71	132
	21	271	72	185
	22	270	71.5	190
	23	2[illegible]	71	160
	24	281	72	155
Eccentric	25	322	70	170
	26	258	73	173
	27	272	68.5	150
	28	263	69	170
	29	258	68	165
	30	272	74	195
	31	260	70	155
	32	254	72	175
	33	275	70.5	180
	34	480	67	150
Control	35	266	67.5	136
	36	282	69.5	165
	37	291	70	190
	38	315	72	190
	39	311	70.5	189
	40	259	69	149